STUDY OF RAINOUT OF RADIOACTIVITY IN ILLINOIS

Ninth Progress Report

Contract Number AT(11-1)-1199

November 1970

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Illinois State Water Survey
at the
University of Illinois
Urbana, Illinois

STUDY OF RAINOUT OF RADIOACTIVITY IN ILLINOIS

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Sponsored by

United States Atomic Energy Commission
Fallout Studies Branch
Division of Biology and Medicine
Washington, D. C.

Richard G. Semonin
Principal Investigator

CONTENTS

INTRODUCTION

The contract research during 1970 was continued along two paths of inquiry. The first of these involved execution of a major field project (ITREX) to release unique chemical tracers into the updrafts of convective clouds and to estimate the scavenging efficiency of such treated clouds. The second and complementary avenue of research dealt with the experimental determination of collection efficiencies of falling drops as a function of their size and electrical charge.

This report summarizes the preliminary findings from both research areas during the past year, and includes the Atmospherics Incorporated flight report as Appendix A. In contrast to the lack of field data collected during 1969, the 1970 project was very successful. There were six storm situations which were treated either with indium and/or lithium during the 6-week research period. A more detailed and thorough treatment of these cases will be presented in a separate Research Report, and the important results will be summarized for publication early in the 1971 contract period.

ACKNOWLEDGMENTS

Many individuals contributed to the success of the field program during the past year, and it seems proper to thank them for their dedication to the difficult task of working with the daily variability common to warm season rainfall conditions in Illinois. John Wilson supervised the operational field crew consisting of Thomas Cislo, Charles Ellington, and William Cordell. This effort to collect the rainwater samples as rapidly as possible after a storm required efforts above and beyond the routine. Without the fine effort expended by these men, the high quality field data would never have been gathered.

The excellent forecasts prepared by Robert Cataneo were invaluable for planning day-by-day operations. The radar scope interpretations by Robert Beebe and Neil Towery provided the knowledge necessary for the rapid decisions that had to be made concerning the release of chemicals into specific clouds. The excellent maintenance of the radars, radios, and associated equipment by

Donald Staggs made it possible to always be in a state of readiness for an experiment. These men devoted themselves to the project seven days a week **with** the result that only one possible cloud case was missed during the 6-week period.

Thanks are also extended to Arthur Bodenschatz of the Survey's Chemistry Section for his carefully conducted analyses of the rainwater samples for the various trace metals.

The overall encouragement of Mr. Stanley A. Changnon, Jr., Acting Head **of** the Atmospheric Sciences Section, during the conduct of the project as **well** as his direct participation in some of the experiments is gratefully acknowledged.

The laboratory studies were carried out under the direction of Dr. John Adam. He was assisted in this undertaking by Antheny Rattonnetti who contributed a great deal to the understanding of the use of spores as an aerosol **for** the experiments.

PROJECT ITREX FIELD STUDY

Introduction

During the period 15 May through 30 June 1970, in cooperation with the Argonne National Laboratory and the University of Michigan, the Illinois TRacer Experiment was continued for the second season. The project was conducted over and within the Water Survey's Central Illinois Network of 196 recording raingages in a 1600-square-mile area.

This type of experiment requires knowledge of the thunderstorm structure, the placement of a unique chemical tracer into a prescribed part of the cloud, and the subsequent analysis of the tracer in the storm rainwater. Through the use of two aircraft, two radars, and a network of ground-based rainwater samplers, most of the requirements were fulfilled.

Aircraft

Two aircraft systems were used during the initial two weeks of the experiment. A Queenaire aircraft, on loan from NCAR (National Center for Atmospheric Research), was used for air sampling at various elevations and also to dispense tracer chemicals at relatively high altitudes at the periphery of stcrnis. This aircraft had the capability of burning four flares from a position beneath the tail structure of the airframe.

The other aircraft, an Aztec, was provided by Ai (Atmospherics Incorporated), under contract with the Water Survey. This aircraft was used to burn flares into low-level updraft of the storms, and had the capability of carrying 12 flares and burning them simultaneously. The services performed by both of these flight crews were invaluable to the success of the program.

Network Instrumentation

The experience gained during the 1969 field operation indicated that the time between deployment and subsequent pickup of the rainwater-collector bag at any one site must be minimized in 1970 to prevent excessive dry fallout of material into the bag. With available funds, facilities, and personnel, it was necessary to decrease the size of the collector network to insure a more rapid pickup of the rainwater samples. Thus, a sub-network of 49 sites within the Central Illinois Network was selected as the primary target area for the 1970 experiments.

The 1970 ITREX network, shown in figure 1, was composed of 49 raingages and rainwater collectors spaced over a 4OO-square-mile area centered approximately at Clinton, Illinois. This particular placement was chosen since the headquarters for the University of Michigan operations was one mile north of Clinton, and therefore, travel was minimized from the field laboratory to any of the collector sites.

The University of Michigan project employed the use of semi-mobile samplers which were deployed in advance of a storm to specific sites depending upon the radar-predicted movement of an individual treated storm. These collectors were of the same type as in the permanent 49-gage network, but were used to increase the density of sampling during the release of the tracer chemicals into storms.

Radar Instrumentation

Two 3.2-cm radars were used on the project as during the 1969 experiment. Both were operated by the Water Survey, and were located east of the raingage network at the site seen in figure 1. The CPS-9 was the primary radar used for surveillance and echo tracking when a storm of interest moved into a chosen "upwind" target area. Automatic gain reduction and continuous PPI

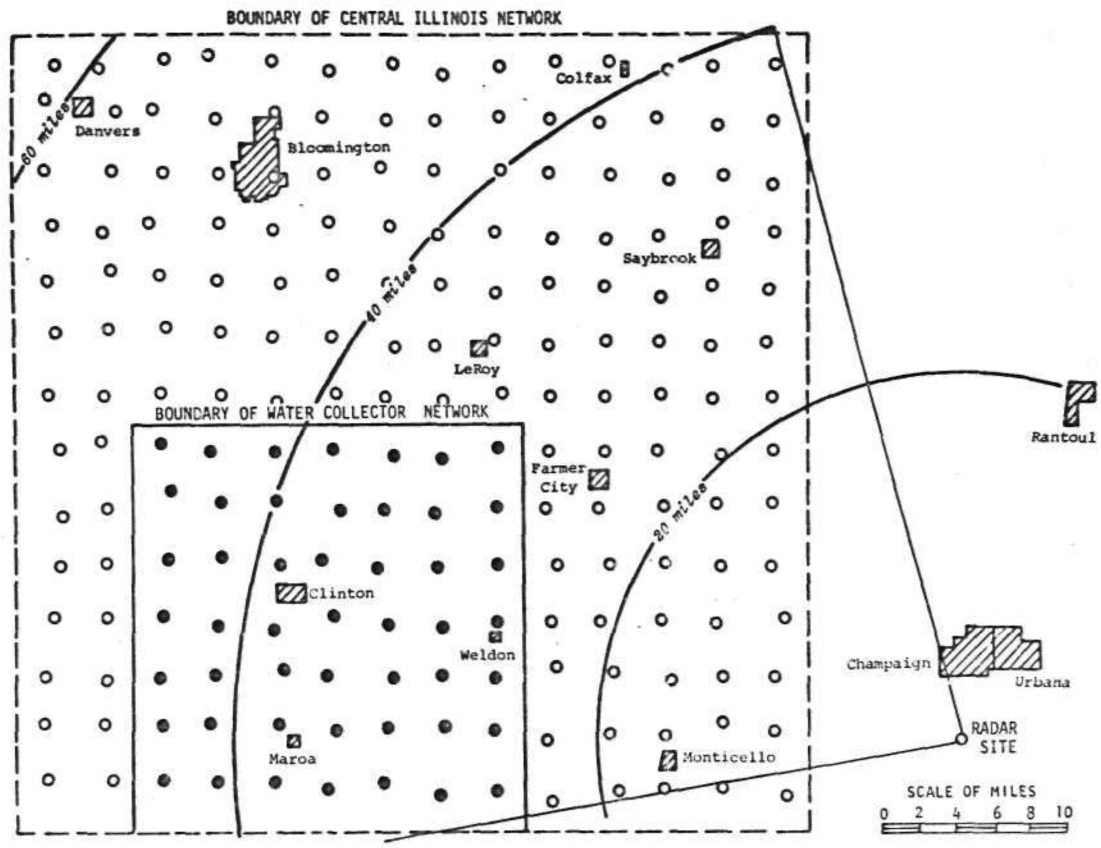

Figure 1. Instrumentation on the Central Illinois Network during Project ITREX in 1970.

photography were used to document echo activity. Polaroid pictures also were taken at regular intervals and were used for staff Debriefing purposes.

The TPS-10 radar was used to provide range-height data on storm growth and decay. This radar was essential in providing the information pertinent to the decision for treating a particular storm. If the storm was in the decay stage, then the aircraft was directed to another target. If the aircraft indicated by radio that a sizable updraft was encountered, then this radar was used to determine the strength of the storm for the purpose of deciding the time of flare ignition. The range height information was also used to examine the effects, if any, of the chemical treatment upon the storm morphology.

Experiment Design

A daily weather briefing was held at the Meteorology Laboratory of the Water Survey at the University of Illinois Airport each morning between 0830 and 0930 CDT. Based upon the atmospheric stability, the output of a predictive numerical cloud model, and the general synoptic weather, a decision was made concerning the daily operations. The da/ was named a "GO" day if the prediction included the formation of convective precipitation during the ensuing daylight hours.

The field crew was sent to deploy bags in the rainwater collectors within two hours of the expected shower development. The radar sets were operated to monitor echo formation and movement, and the flight crews and aircraft were prepared for a mission. The University of Michigan group in the Clinton area was notified of the daily prediction and was asked to stand by for additional information as echoes developed.

The first echoes that appeared were used to determine the average motion of individual storms. Based upon this information, a "target area" immediately upwind of the ITREX network was indicated on the face of the operational radar scope. The target area was that within which the aircraft would intercept a storm moving over the collector network. This approach allowed for the storm travel during the time that the tracer material circulated into the storm and was removed by precipitation. The aircraft was dispatched to the area at the discretion of the Project Director. The final decision concerning the ignition of the pyrotechnics rested with the flight crew and their ability to discern an updraft associated with the storm of interest.

Subsequent to the release of a chemical tracer into a storm, the coordinates of the aircraft were relayed to the radar operators and the associated radar echo was then carefully observed until the treated storm passed out of the network.

The field crew was again activated to retrieve the rain samples within two hours of the ignition of the flares. All of the rainwater samples were returned to the University of Michigan Clinton Laboratory where individual aliquots were pretreated with acid and then transported to the Water Survey's Chemistry Section for the atomic absorption analysis for trace metals.

The flight crew was debriefed after a mission and a discussion between the radar operators and the flight-meteorologist was held to improve techniques for future experiments. In this way, the program was constantly updated to incorporate the experience of each previous case. A summary of the daily operations and the flight observations is presented by Atmospherics Incorporated in Appendix A.

Weather During Field Operational Period

After light precipitation on 15 May, the next 7 days were characterized by westerly flow as an upper ridge moved slowly across the country. As a result of this pattern, the atmosphere was quite stable in the Midwest and no significant precipitation occurred during this period. There were no "GO" days forecast for this time.

By 23 May, the ridge shifted sufficiently eastward to allow moist, unstable air to flow northward from the Gulf of Mexico. This flow persisted until 25 May when the upper air flow veered to the west as a trough moved through the Midwest, bringing in drier and more stable air. "GO" days were forecast for the 23-25 May period and the first flares were burned into a storm on *2k* May.

A return to moist, unstable flow from the south occurred from 28 May through 2 June. Three "GO" days were forecast during this period with burns on 30 May and 1 June.

The weather pattern for 2 June through 5 June was influenced by a low pressure area, closed at 500-mb, which moved very slowly eastward from Oklahoma during the period. Light rain showers with no significant convective activity occurred in the Midwest during this time. A ridge of high pressure prevailed thereafter during 7~H June with the center moving across the Midwest. Dry, stable conditions were associated with this pattern. There were no "GO" days and no flares burned from 2 June to 11 June. A deep trough aloft moved inland from the Pacific Ocean and it became associated with a stationary frontal pattern in the Midwest. This change in upper air flow resulted in the return of moist, unstable conditions ia the central portion of the country during the ensuing six days. Convective activity was quite evident during 14-15 June and several strong thunderstorms occurred on those days. "GO" days were forecast and burns were made on 14 and 15 June.

Except for a minor trough which moved through the area on 20-21 June, the remainder of the month was dry with stable conditions dominated by a warm, strong ridge over the Midwest. Four "GO" days were forecast during 16-30 June, one of which resulted in a flare burn on 20 June.

Figure 2 shows the percent of normal precipitation which fell throughout Illinois during the 1970 Project ITREX field study period. Daily precipitation data from 90 U. S. Weather Bureau climatological observers were used to construct the map. Rainfall was generally above normal in Illinois during this period, with a narrow band of sub-normal amounts through the central section of the state. The 75% isolines have been drawn in the below-normal area to enhance the pattern.

In the Central Illinois Network, precipitation ranged from about 60% of normal in the northeast to nearly 150% of normal in the west. Clinton, located southwest of the network center, received 87% of its normal 18 May-30 June rainfall during Project ITREX.

Numerical Cloud Modeling

A slightly modified version of the steady-state, one-dimensional cloud model developed by Weinstein and Davis (1968) (hereafter referred to as WD) was used during the field operations as an aid for the daily prediction of convective activity.

The first modification was to linearize the release of the latent heat of fusion throughout a prescribed depth of the cloud (-15°C to -25°C). The original version of the WD model involved the release of latent heat instantaneously at a single level. The second change in the model concerned the fallout of hydrometeor water. The model would not permit fallout to occur

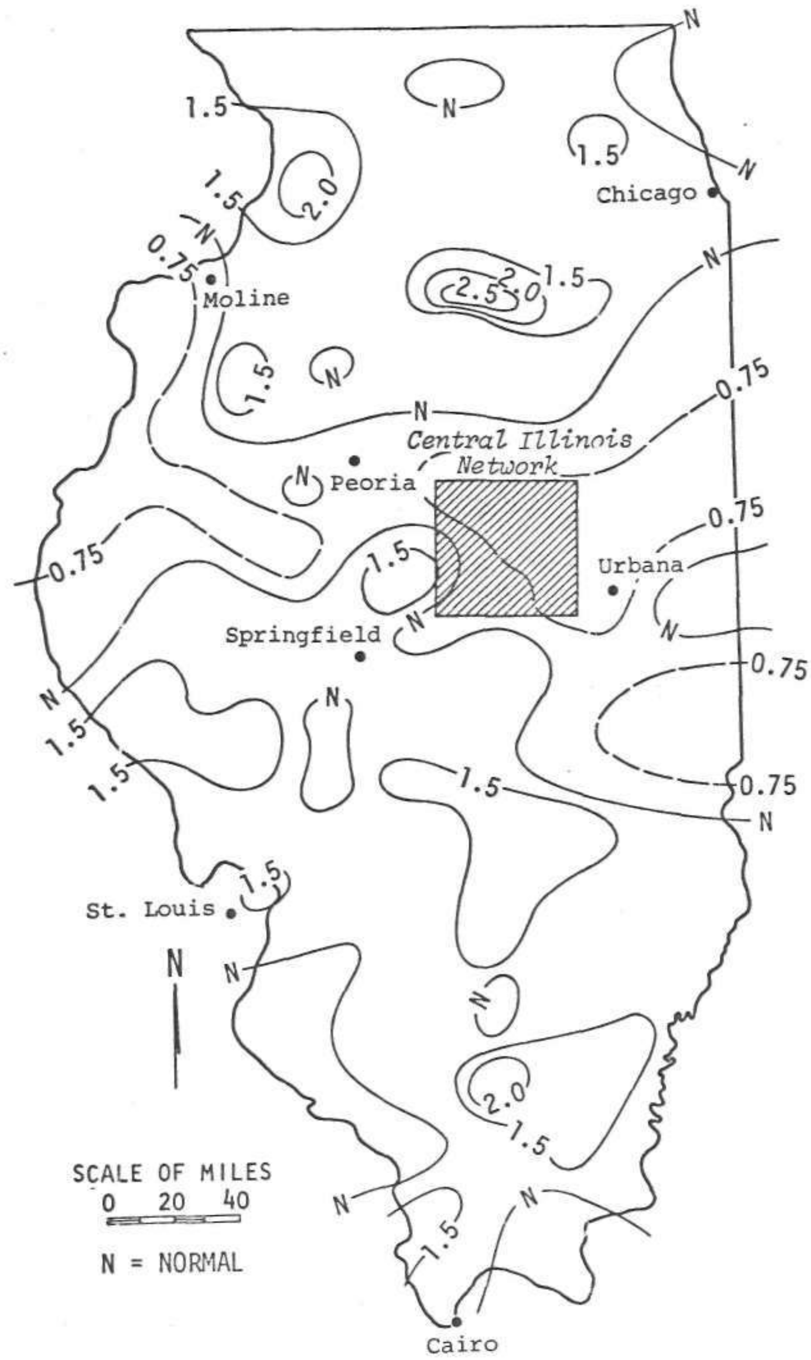

Figure 2. The ratio of the observed to the normal rainfall in Illinois during the period 18 May through 30 June 1970.

when the calculated updraft velocity exceeded the terminal velocity of the median drop size in the derived Marshall-Palmer distribution. A more realistic approach was presented by Simpson and Wiggert (1969) and was adopted for this work. This modification assumes that the cloud behaves like a Hills vortex and that the water leaves the vortical circulation after falling a distance "R". This change prevented water loading of the updraft and permitted more realistic estimates of updraft radius which were compatible with the RHI radar echo diameter and height.

The 0700 CDT soundings from Peoria and Salem were used as input for the model. The computer program was executed on the IBM 360/75 computer system of the University of Illinois. The results from the computer model were available within an hour after submission of the data.

The ITREX operational network was located 50 miles southeast and 100 miles north of the Peoria and Salem radiosonde stations, respectively. The Peoria sounding was used most frequently, but on occasion when frontal systems intervened the Salem sounding was more representative of the atmospheric structure over the project area.

Since no in-cloud data were taken by aircraft to verify the model predictions, the assessment of the model was based upon a comparison between the computed cloud tops and the maximum height of the observed radar echoes. The verification of the model was accomplished by choosing a sounding "effect" area and noting the maximum echo top within the area using either the TPS-10 observations or those from the U. S. Weather Bureau Radar Summary map.

The "effect" area was chosen somewhat artibrarily as 50 miles either side of a line 150 miles long parallel to the mean flow between 850- and 500-mb at Peoria.

One of the required initial conditions for the operation of the model was an estimate of the diameter of the convective updraft. Since the radar data were often inadequate for determining the horizontal extent of the echoes because of their conglomerating tendency and irregular shape, several radii were used as input for the model. However, from the analysis of the results, the 5-km radius appeared as the best predictor of the maximum tops for all cases. The results are shown in figure 3. It is apparent that the model was able to predict rather closely the maximum vertical development throughout the test period. The comparison between the predicted and observed cloud

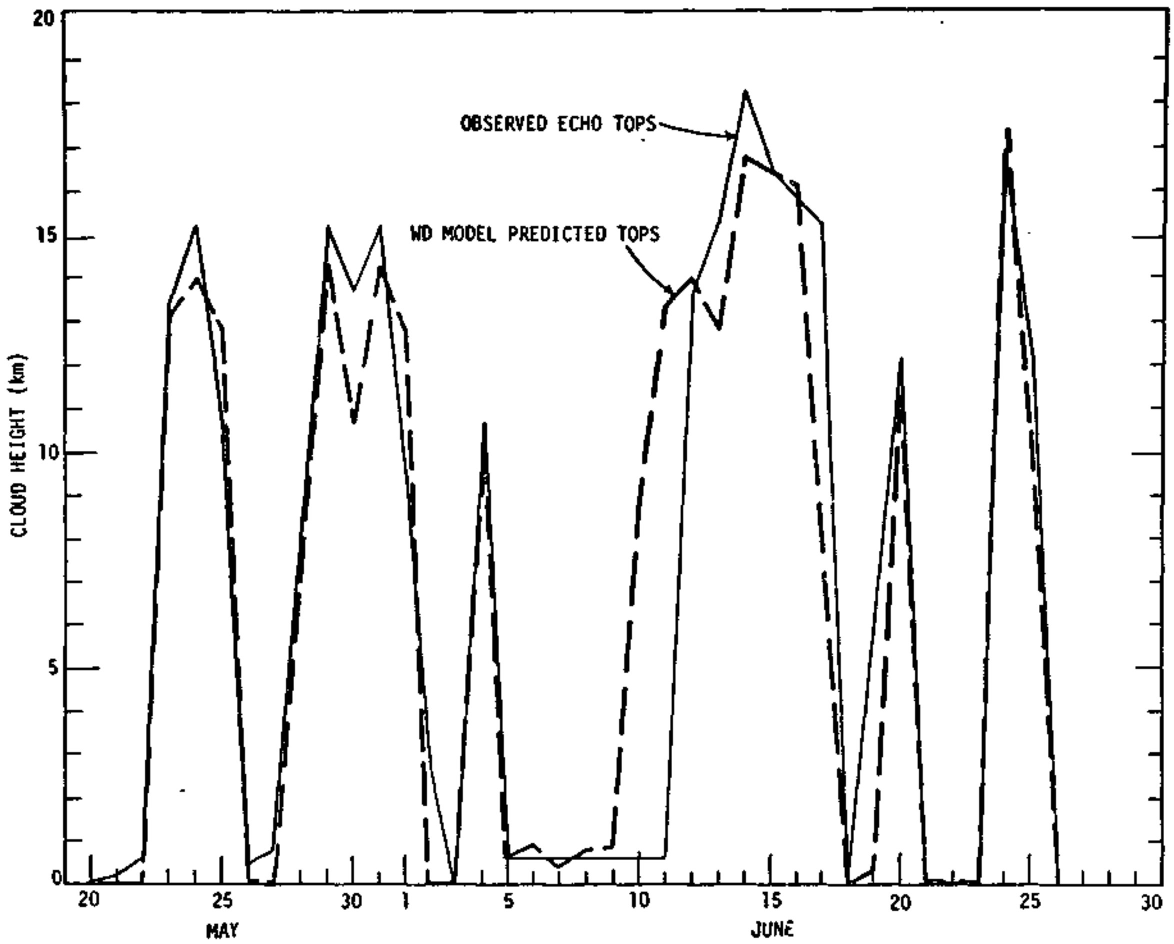

Figure 3. A comparison between numerically predicted cloud tops and observed radar echo tops during Project ITREX.

heights is not too reliable for cloud tops below 3-km since no radar data were available for such small vertical development and the tops were estimated visually.

The success of the model as a forecast tool is illustrated by the fact that every "GO" day was predicted correctly by the model as days of strong convective activity. However, the model predicted tops of 10- to 15-km for 10 and 11 June, which also were forecast as possible "GO" days, but only small cumulus were observed. On these two days rapid drying between 850- and 750-mb took place and this inhibited development.

Although the model was not used to predict the spatial distribution of storms, a qualitative correlation was found between the occurrence of high tops and the number of strong cells in the sounding "effect" area. For example, the period of greatest radar echo activity during the project was between 14 and 17 June. As shown in figure 3, this time interval corresponded with the period of maximum tops during Project ITREX. Within this 4-day period there was one tornado day, two hail days, and two days with funnel clouds reported in the downstream effect region. This may be explained by the strong synoptic-scale low-level moisture penetration and its convergence in the area where storm meso-organization occurred, particularly on 15 and 16 June.

The predicted model profiles of various in-cloud variables for individua storm days are shown in figures 4-8. The radius of the updraft for each of the storms in which chemicals were released was determined as the average of the RHI radar profile above 3-km. On 14 and 15 June the RHI radar camera was inactive and the updraft radius was determined as one-fourth of the area indicated by the PPI echo at maximum development. It should be pointed out that the profiles shown for 15 June resulted from the use of a variable 10-km updraft radius and no hydrometeor water fallout. This model yielded approximately the same maximum vertical speed and height as a constant 5~km radius updraft, partly due to water loading in the upper portion of the cloud.

The success of this model as a predictor of convective activity is encouraging. The microphysics of the model are presently under investigation to include the collection of aerosol by the precipitation particles. Further development will also include the in-cloud scavenging and will provide a tool

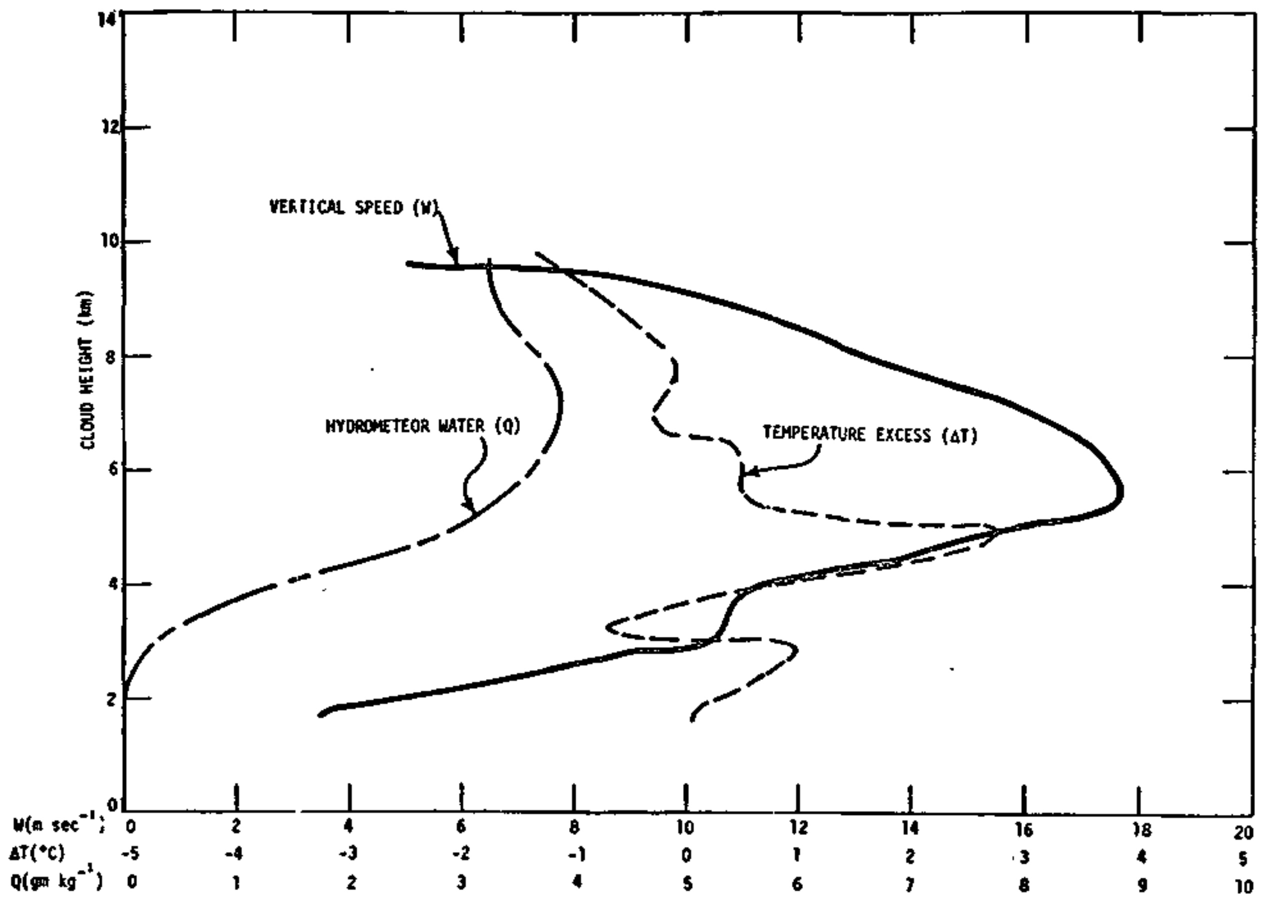

Figure 4. Predicted cloud core parameters for the modified WD cloud model with a 1.5-km updraft radius using the 0700 CDT Peoria sounding for 24 May 1970.

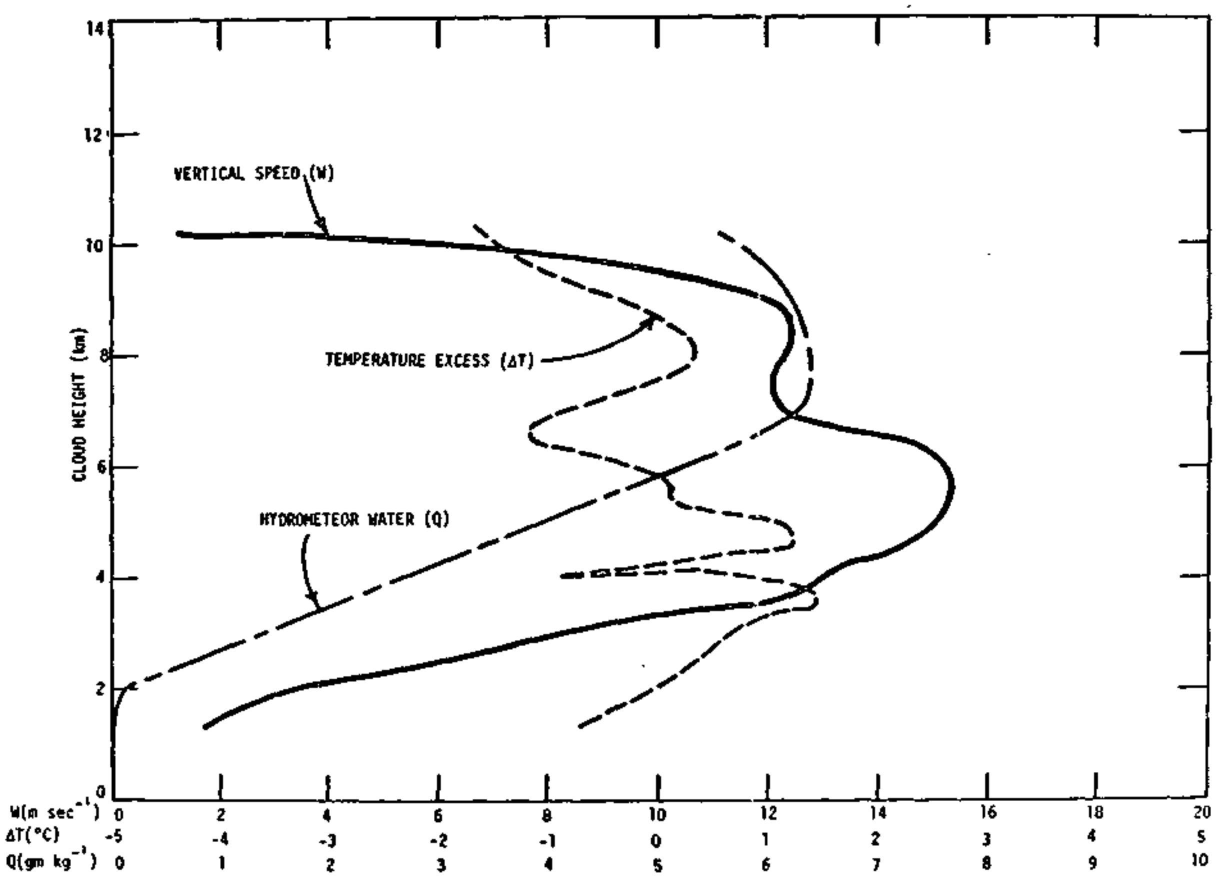

Figure 5. Predicted cloud core parameters for the modified WD cloud model with a 5-km updraft radius using the 0700 CDT Peoria sounding for 30 May 1970.

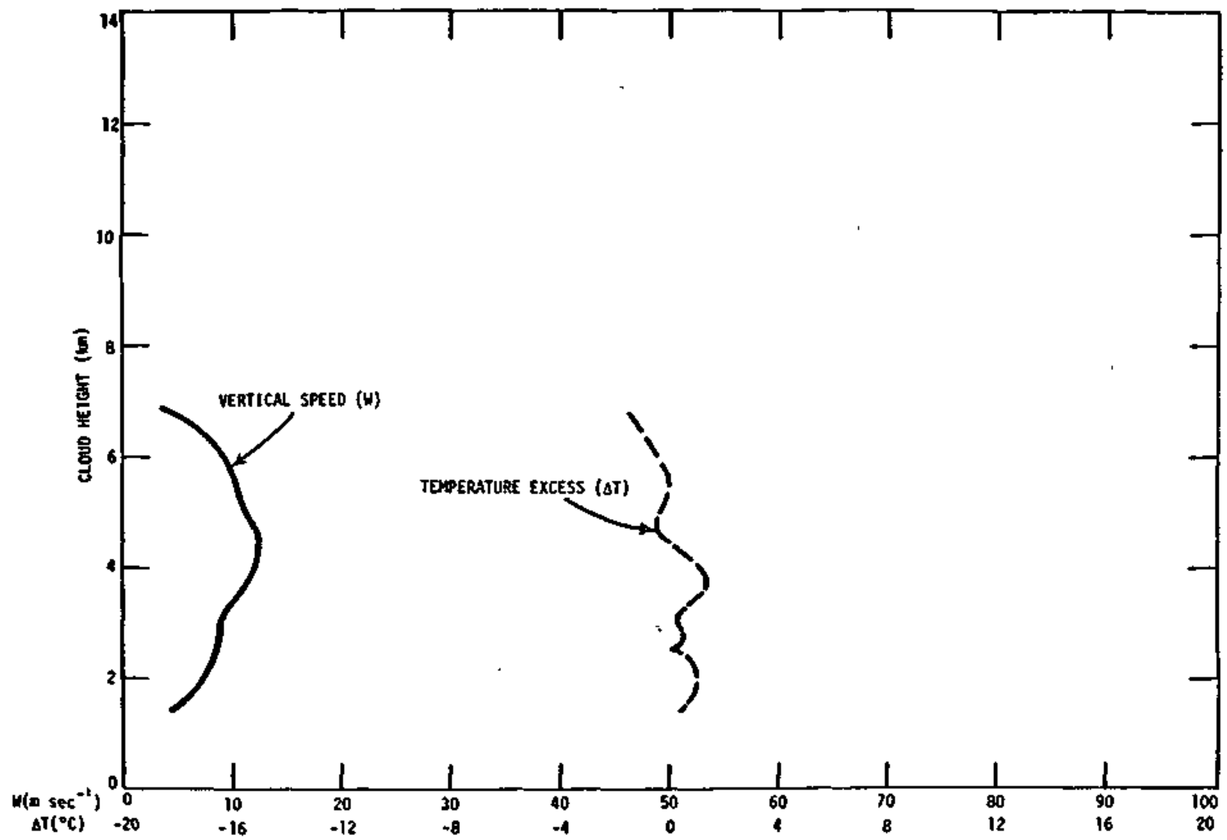

Figure 6. Predicted cloud core parameters for the modified WD cloud model with a 1.5-km updraft radius using the 0700 CDT Salem sounding for 1 June 1970.

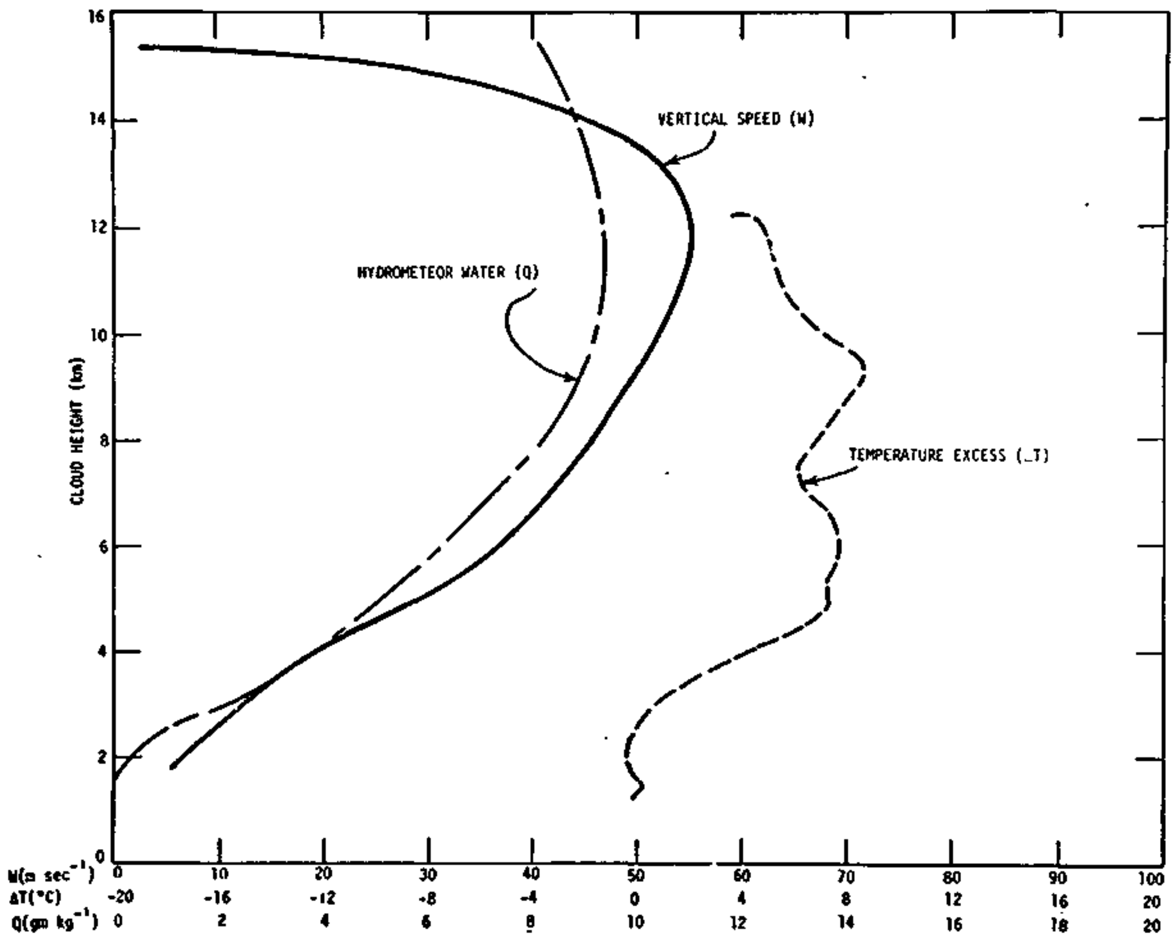

Figure 7. Predicted cloud core parameters for the modified WD cloud model with a 5-km updraft radius using the 0700 CDT Peoria sounding for 14 June 1970.

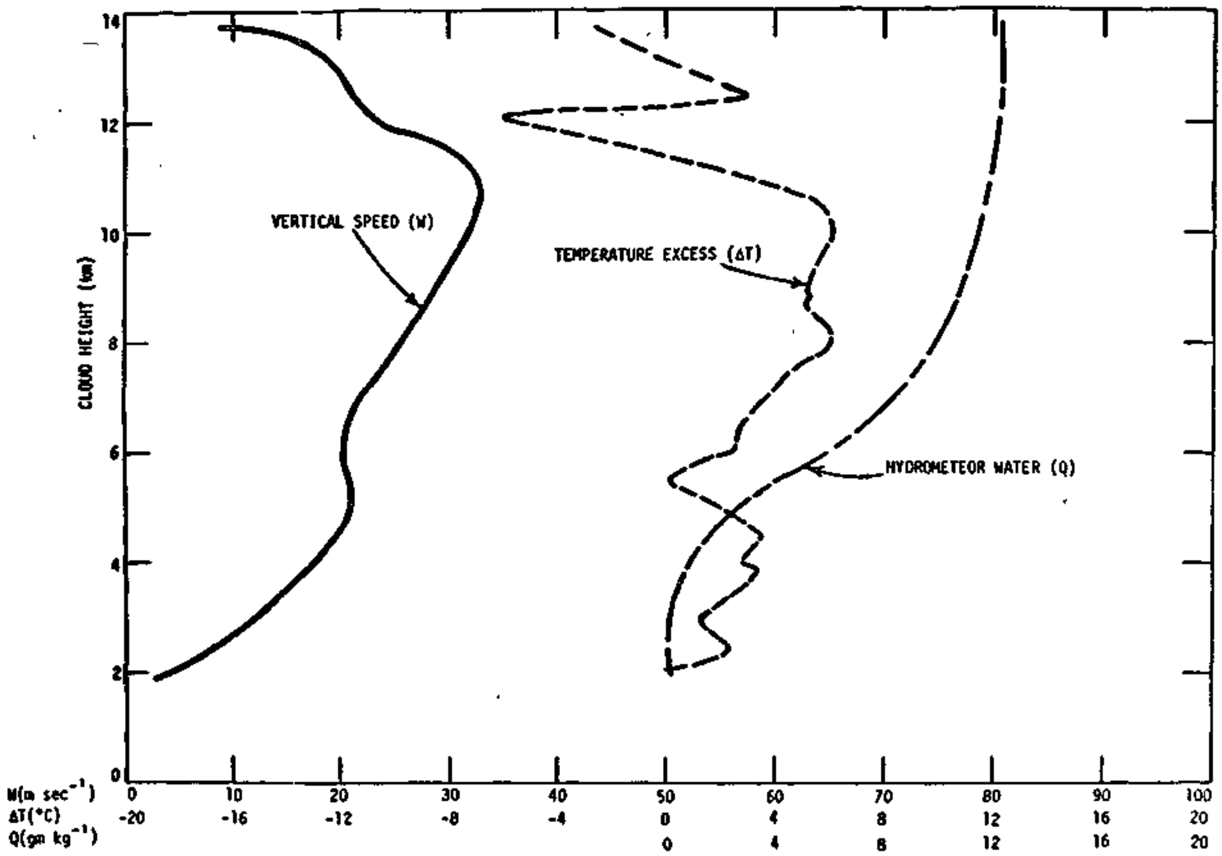

Figure 8. Predicted cloud core parameters for the modified WD cloud model with a 10-km variable updraft radius using the 0700 CDT Peoria sounding for 15 June 1970.

for the prediction of the total scavenging of particulate materials by cloud processes.

Case Studies

The following discussions of individual cases are related only to the analyses of trace metals by the atomic absorption spectrophotometry technique. An additional storm situation on 30 May in which 4 indium flares were ignited is not included hete because no water samples were obtained by the Water Survey. The treatment of this case and all of the indium analyses will be undertaken by the University of Michigan under the direction of Professor A. N. Dingle. A flight on 5 June was conducted by both the Queenaire and the Aztec to obtain aerosol samples by electrostatic precipitator and cascade impactor techniques. These data will also be treated by Professor Dingle.

The University of Michigan work will be summarized separately by Professor Dingle and is not touched upon in this report.

Dry Fallout 7~8 May 1970. In order to estimate the natural background concentration of lithium, sodium, magnesium, and potassium, bags were in-, stalled in 46 rainwater collectors and exposed for a 24-hour period. The weather during this time was clear and dry with little formation of dew in the early morning hours. A relatively weak warm front passed through the area during this period, but resulted in inconsequential cloudiness. The winds were generally light from the south during the entire 24 hours.

A comparison between the deposition patterns shown in figure 9 indicates very little correlation between the various metals. The lithium deposition during this period was non-existent and confidence was enhanced in its use as a unique tracer. There is the suggestion of a persistent relatively high deposition between the cities of Clinton and Farmer City for all three of the elements shown in figure 9. Another high deposition area is indicated south of Clinton near the edge of the network. These are the only two features on figure 9 which reveal any relationship between elements. These two high areas may be attributable to local sources, particularly since similar patterns occurred on some of the tracer-release cases (see figures 9 and 11).

Tracer Case 24 May 1970. Following the retreat of a polar air mass toward the middle-Atlantic states, a fresh outbreak of cool Canadian air

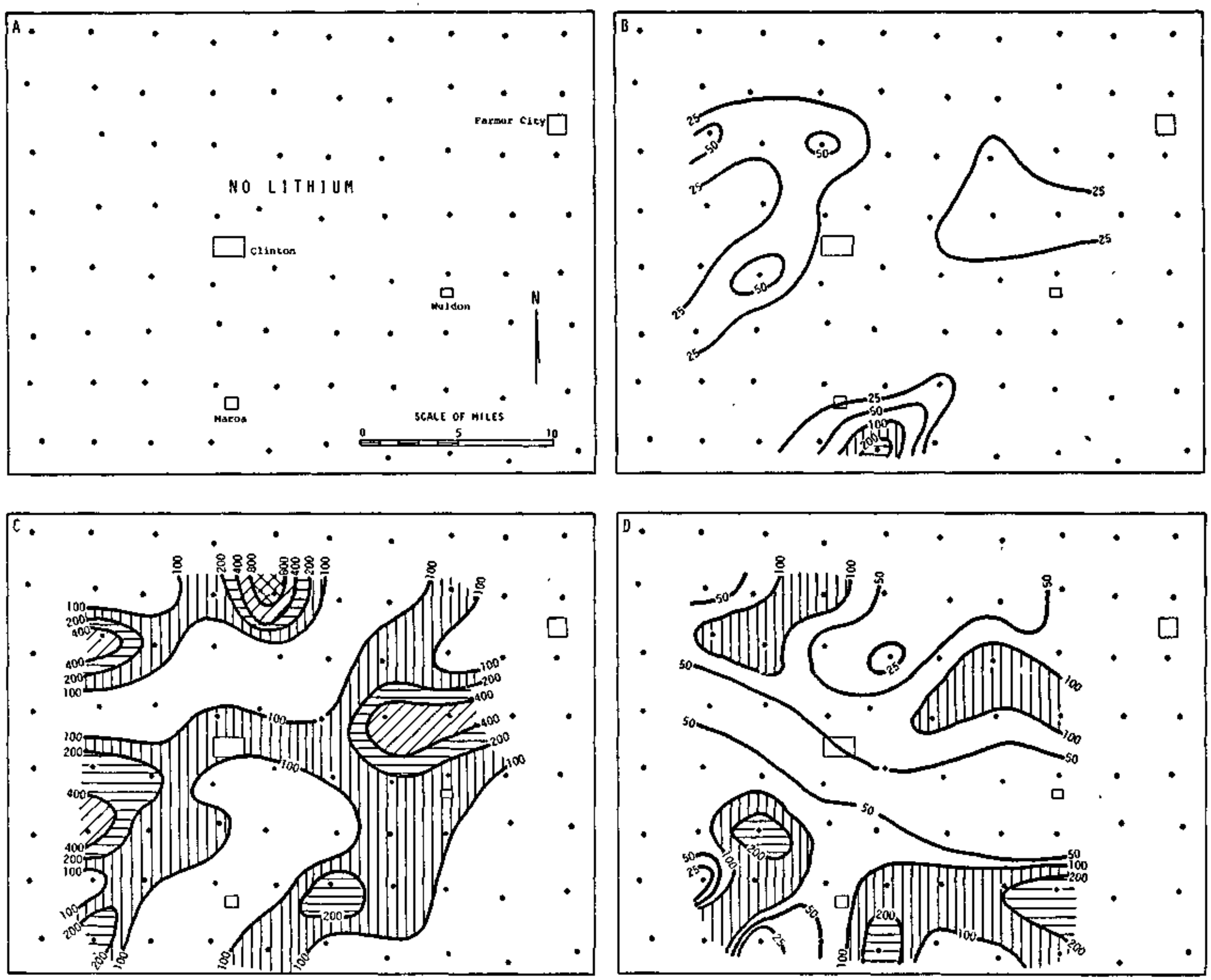

Figure 9. The dry fallout deposition in ng cm^{-2} for a 24-hour period, 7-8 May, 1970, for the following elements: a) lithium; b) sodium; c) magnesium; and d) potassium.

began to push into the upper Midwest. The associated frontal system stalied in the northern part of Illinois and became an east-west stationary front by 23 May. The frequency of convective cloud activity increased with the enhanced southerly flow into the state. By 24 May, the layer below 1.5-km contained sufficient moisture to support a forecast for an operational day. The-computer model predicted maximum cloud tops of greater than 15-km. The field crew was dispatched to deploy bags on the rainwater collector network and the University of Michigan group was alerted to the possibility of a tracer release mission.

The Aztec aircraft was sent to the predicted intercept area west of Clinton at 1357 CDT in anticipation of convective development. The NCAR Queenaire was instructed to obtain air samples for analysis of the storm environmental background concentrations of various elements.

The storms moved from the WSW and appeared to dissipate along the western edge of the network by 1730 CDT. A storm, as indicated by radar at 1755 CDT at the southwestern edge of the ITREX network, was forecast to move across several collectors. The Aztec ignited flares into the leading edge of the storm which at the time was 3.2-km high and growing. The trajectory of this storm was such that it passed over the extreme southeast corner of the ITREX network and only 28 rainwater samples were collected for analysis.

The deposition calculated from the chemical determination of the concentration in the rainwater for lithium, sodium, magnesium, and potassium are shown in figure 10. The flight track of the Aztec aircraft is indicated in figure 10a, and the duration of the burn is shown as a solid line along a portion of the flight track.

An interesting feature of the deposition pattern for this case is the relatively high values of all four elements in the vicinity of the point of flare ignition. A secondary maximum is also observed downstream from the point of flare burn at the eastern edge of the network. The storm, as mentioned before, moved to the ENE, and the general low-level flow was from the southwest. Under these conditions, it is difficult to explain the deposition west of the burn. Similar conditions will be noted in some of the other tracer cases to be described. This observation suggests that the materials were transported upward in the cloud into a region of strong horizontal divergence where the chemicals were ingested into neighboring rain-generation

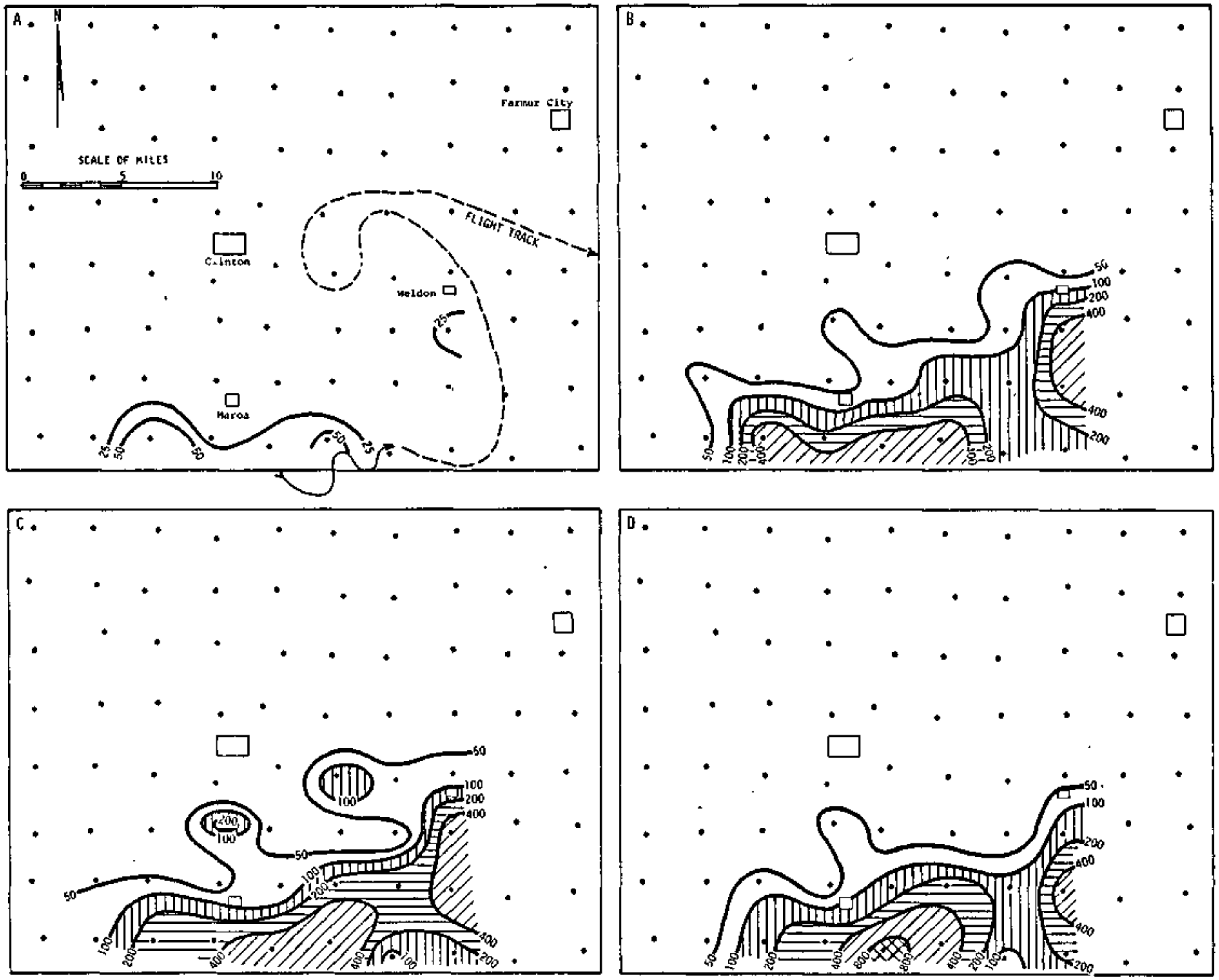

Figure 10. The thunderstorm deposition in ng cm^{-2} for 24 May 1970, for the following elements: a) lithium; b) sodium; c) magnesium; and d) potassium. The solid line indicates the flare burn duration along the dashed flight path.

regions. Other cells followed along and to the rear of the storm cell treated on 24 May.

Tracer Case 1 June 1970. A weak cold front, oriented nearly north-south in western Illinois, moved slowly eastward during the day accompanied with showers and thundershowers. Early morning stratus clouds prevented heating of the surface and delayed the development of convective showers until late in the day.

Both aircraft were readied with 4 litKium flares on the Queenaire and 12 indium flares on the Aztec. By 1530 CDT echoes were indicated moving towards the network and both aircraft were dispatched at 1600 CDT to an area west of Clinton. The Queenaire attained an altitude of 14,000 feet, and commenced the burn of the four lithium flares at 1637 CDT, as shown in figure 11a. The Aztec, at the base of the same cloud, observed a weak updraft of 300 feet per minute and flares were ignited at 1639 CDT. The flight and burn track of the Aztec is also shown in figure 11a.

Both of the aircraft were in cloudiness and occasional showers during the mission. Because of the adverse weather conditions, the Queenaire, under advisement from the Chicago FAA control center, cleared the area, and was followed by the Aztec after a short period.

The individual storms were moving rapidly from the SSW and the treated storms were nearly dissipated by the time they had traversed the network. The radar display indicated that the Queenaire burned its flares into the upper backside of the same storm which was treated at low level by the Aztec. The NNE movement of the storm is reflected in the orientation of the deposition patterns shown in figure 11. The small area of high values near the east edge of the network occurred at a much later time than the depositions on the western half of the network.

There is a maximum of deposited material in the southwest corner of the network which may be associated with the positions of the two aircraft at the time of flare ignition. However, the secondary maximum in the north-central portion of the network must have occurred at a later time. The material deposited in this "high value" region must have resulted from the transport of the tracer chemical into the cloud and the subsequent release of the material with the rainfall. A high deposition area can also be noted at the southern edge of the network where rain from the treated cell did not occur.

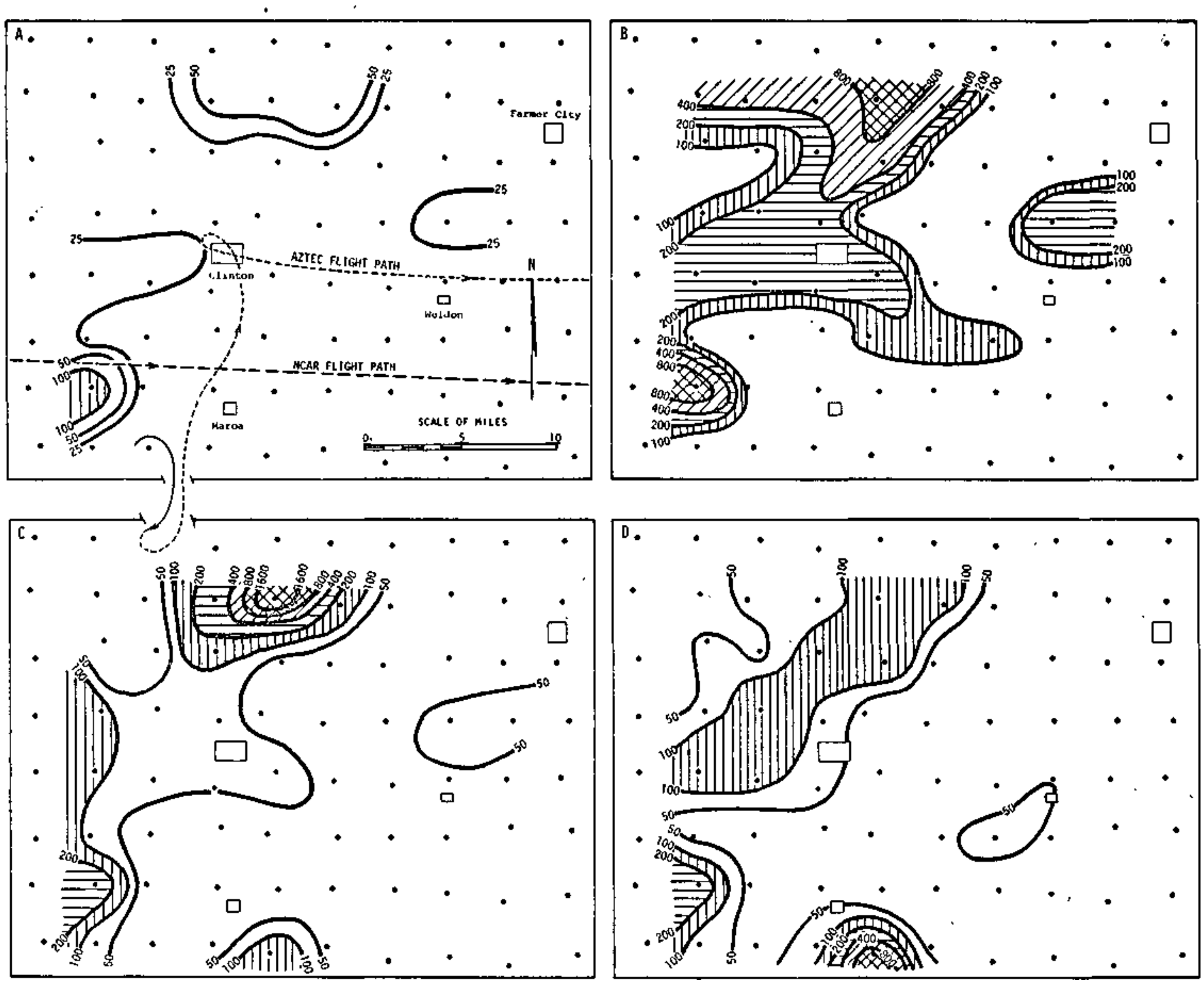

Figure 11. The thunderstorm deposition in ng cm^{-2} for 1 June 1970, for the following elements: a) lithium; b) sodium; c) magnesium; and d) potassium. The solid line indicates the flare burn duration along the dashed flight path,

This, as in the 24 May case, suggests the transport of the chemicals between clouds at an upper level.

The results for 1 June qualitatively agree with the pattern generated on the 24 May case, that is, high values in the immediate vicinity of the flare burn, then a secondary high downstream, and isolated highs distinctly away from the burn and the treated storm.

Tracer Case 14 June 1970. An east-west stationary front extending westward across northern Illinois to a wave in the Colorado region dominated the weather for a 48-hour period. Moist air from the Gulf of Mexico moved into Illinois resulting in a decrease in stability. The forecast indicated an excellent opportunity for a mission after the dissipation of early morning fog.

The computer model predicted cloud tops in excess of 16-km. This prediction was nearly verified by radar observations in the morning when scattered thunderstorms were observed with tops of greater than 18-km. Several storms passed through the experimental area in the morning, but they were not suitable for study since none of the network bagging operations had been completed at this time.

The Aztec aircraft was sent to intercept an echo and search for strong updrafts in the system at 1330 CDT. Due to extremely poor visibility, the flight crew experienced some difficulty in visually monitoring the storm activity. Tornadoes were reported in association with this squall line as it moved through central Illinois. The termination of the flare burn was in the presence of heavy precipitation, and only lignt updrafts were encountered during the flight along the eastern side of the line of thunderstorms.

The line of thunderstorms, which was oriented north-south to the west of the network, split into two parts as it approached the western edge. The northern half of the line, which contained the treated cell, continued to move eastward across the network and dissipated in the central portion. The southern half of the line stagnated for a brief period and then strengthened and began to more through the central and southern portions of the network. It was the rain from this regeneration of the line that brought the heaviest depositions on the network.

The deposition pattern shown in figure 12 is an interesting example of the usefulness of the tracer technique in describing storm activity. As in

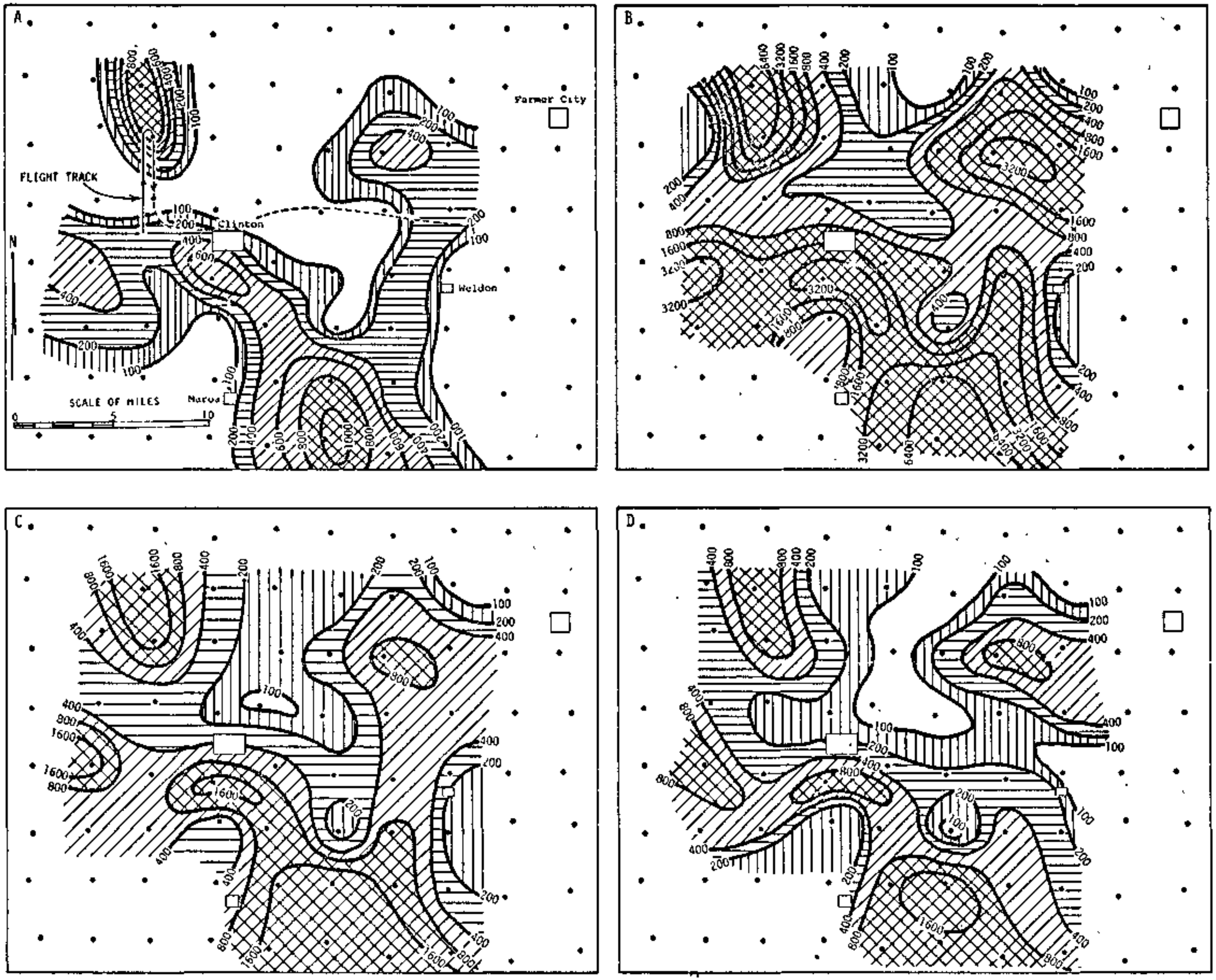

Figure 12. The thunderstorm deposition in ng cm^{-2} for 14 June 1970, for the following elements: a) lithium; b) sodium; c) magnesium; and d) potassium. The solid line indicates the flare burn duration along the dashed flight path.

the previous two cases, the area of high deposition values noted to the northwest was closely associated with the aircraft position at the time of ignition of the flares. However, the remaining pattern of high deposition occurred with rain that fell at a much later time. The extremely high value in the south central part of the network was associated with rain that did not fall in that area until 104 minutes after the flare burn. Again the data appear to indicate a lateral spreading of the chemicals between the various precipitation formation cells in the line. This horizontal mixing must occur at high levels since the individual radar echoes showed no connection at low levels.

Tracer Case 15 June 1970. A stationary frontal system through northern Illinois extended westward to a low centered in north-central Nebraska. The entire situation was very similar to the case of 14 June. An operational day was forecast and the computer model predicted cloud tops to 16-km.

The Aztec aircraft was sent to observe a line of convective cells approaching Clinton from the west. Updrafts in excess of 1500 feet per minute were observed along the leading edge of the line at 1520 CDT. Extremely heavy precipitation was recorded at the University of Michigan Laboratory at the time of the treatment and the cloud into which the tracer was released moved through the area immediately following the heaviest shower.

The preliminary deposition pattern shown in figure 13 again illustrates the interesting behavior of the flare-associated chemicals introduced into the updraft. It is somewhat premature to present this case since much of the data for the southwestern portion of the network are still under investigation. Due to the severity of the weather conditions associated with this case, the rainwater samples from the southwestern portion of the Survey"s network in the southwestern area were not collected. However, some samples for this area are available from the intermediate network of the University of Michigan, but these must be individually analyzed with respect to the rainfall as indicated by the surrounding raingages.

The radar depiction of the storms during and following the burn period are not reliable due to attenuation from heavy intervening rain between the radar site and the treated storm.

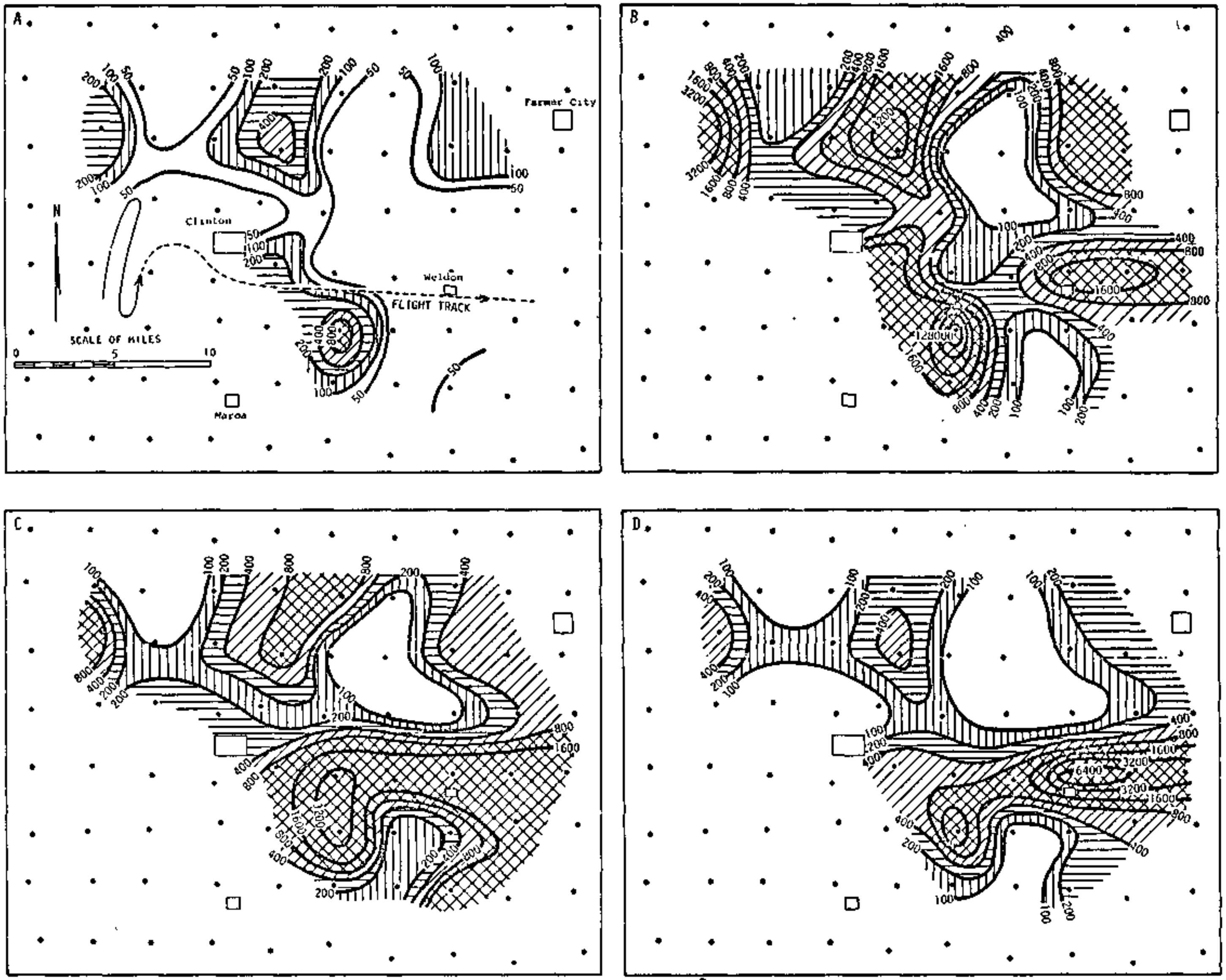

Figure 13. The thunderstorm deposition in ng cm^{-2} for 15 June 1970, for the following elements: a) lithium; b) sodium; c) magnesium; and d) potassium. The solid line indicates the flare burn duration along the dashed flight path.

The tracer chemicals were dispersed over a very large area as shown by the high deposition of material perpendicular to the direction of movement of the line of thunderstorms. The implication of this pattern of deposition is that the material was rapidly mixed in the horizontal across the boundaries between rain cells. This further implied, as in the previously described cases, that the Illinois storm systems are closely interrelated at an upper level.

Tracer Case 20 June 1970. A very shallow, high pressure system was centered over Iowa on 19 June and moved to the east during the next 24 hours. A weak warm front appeared through the northern plains states and joined to a stationary front through northern Oklahoma forming a wave-like pattern.

The synoptic situation was conducive to the formation of steady rain with intermittent thundershowers throughout the day. The desirability of obtaining data during a stable rain situation resulted in the release of chemicals on this day. The radar indicated a continuous, light, steady rain area moving to the east approaching the network during the middle afternoon. Convective activity was observed by radar to the north of the ITREX network, but at the time of flare ignition was considered to be sufficiently far away as not to influence the sub-cloud scavenging over the network.

The Aztec was dispatched at 1640 CDT after the rain area had covered half of the network area. The flight plan called for a straight east-west flight path from the western edge of the network with the termination of the burn 12 miles southeast of Clinton. The flight log indicates that the aircraft was in steady rain during the burn and encountered little turbulence.

The deposition pattern in figure 14 shows a maximum in the vicinity of the flare ignition with high values indicated perpendicular to the flight path and also downstream (east) in the direction of motion of the rain area. As in all of the previous cases the tracer material was found to have dispersed over a broad area, which suggests that the material was ingested into the cloud system and transported horizontally through the rain generation volume. A closer examination of this case is necessary to discern the possible influence of the convective activity in proximity to the network.

Summary of Tracer Cases

A surprising feature of each of the deposition patterns is the great similarity of the area! distribution of the four elements studied. The

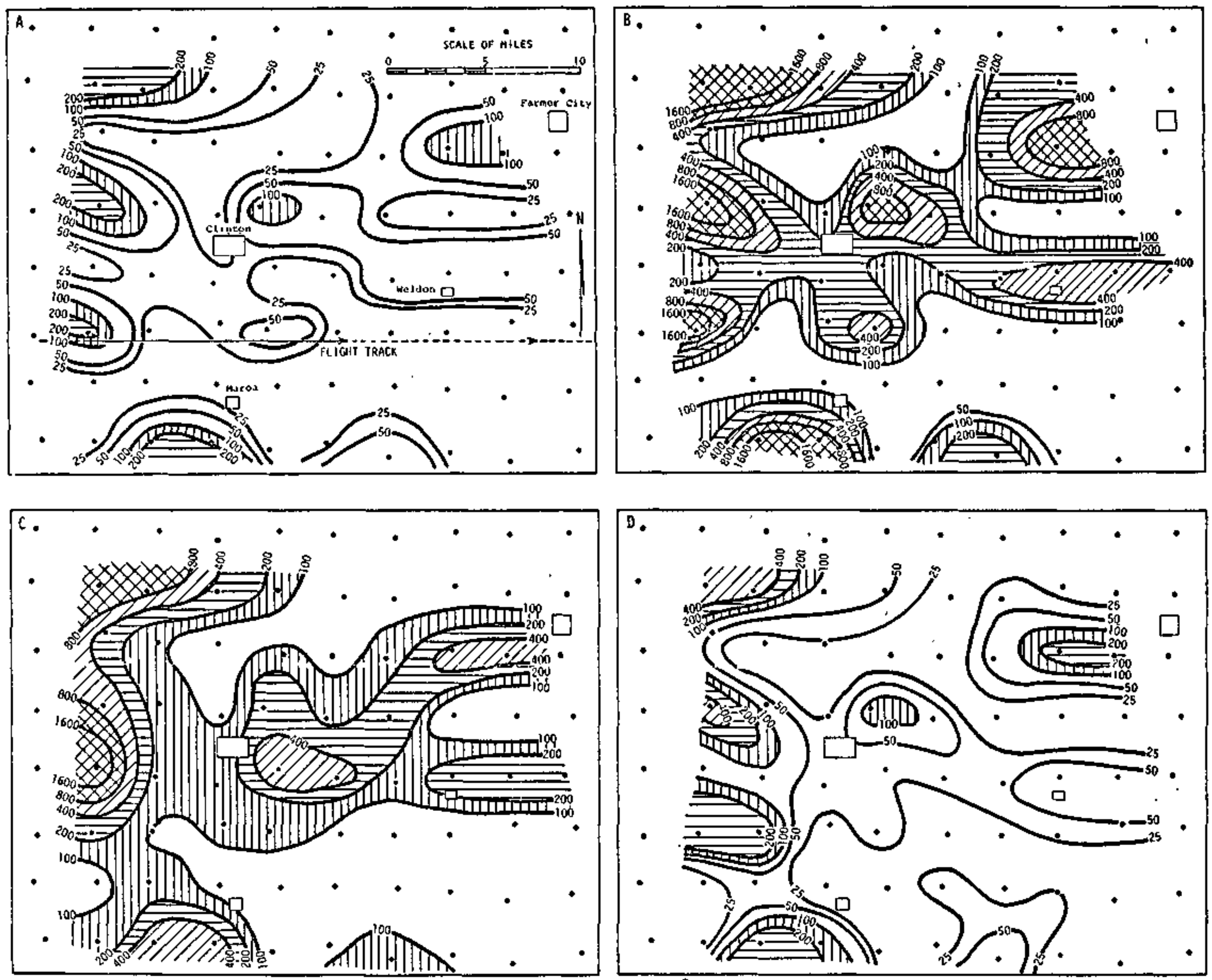

Figure 14. The stable rain deposition in ng cm^{-2} for 20 June 1970, for the following elements: a) lithium; b) sodium; c) magnesium; and d) potassium. The solid line indicates the flare burn duration along the dashed flight path.

llthium flare. howe/er, contained sodium nitrate, magnesium, and lithium. Therefore, there were three tracers involved in a single flare. Furthermore, the correlation coefficient between the lithium and sodium values for all of the cases is greater than 0.90 which indicates that the elements are chemically complexed in the flare effluent and are removed by the rain in the same way. The indium flares contained potassium and therefore, while the three elements, sodium, potassium, and magnesium were chosen to represent the background tracer material, the result is that all of the elements chosen for analysis were present in the flares.

In private conversation with researchers at the Naval Weapons Center, China Lake, California, it was suggested that the lithium flare mix would result in sodium-lithium complexes, but that the magnesium would form magnesium oxide which is totally insoluble in water. Yet, the removal process for the magnesium and the lithium-sodium complex appears to be the same since the ground distributions are nearly identical.

An interesting qualitative observation appears from examination of the various deposition patterns with respect to the storm movement. The average distance between the cells of high deposition, perpendicular to their motion, on 14, 15, and 20 June is 11-km. Assuming that this distance represents an entire cell diameter, it corresponds approximately to the 5"km updraft radius which was very successful in numerically predicting cloud heights.

It must be emphasized that the foregoing discussion is preliminary and the final detailed analyses and interpretations must await additional study of the rainfal1-time distribution subsequent to the burn; the incorporation of the University of Michigan samples; the analysis of air filtration samples obtained with the NCAR aircraft; and the chemical analysis of the time samples obtained by the Argonne National Laboratory. The continuing analyses will include an estimation of the total tracer deposited on the ground through the technique of planimetering the contours of the patterns.

Further analyses will also include determinations of the ratio between the various chemicals to ascertain the regions where the unmodified flare effluent was deposited (ratio Li/Na = 0.4), and where environmental sodium entered into the deposition. The ratios of the remaining elements will also be examined for significant trends in their behavior.

LABORATORY STUDIES ON THE SCAVENGING OF ATMOSPHERIC PARTICLES

Introduction

A laboratory study of the removal of atmospheric aerosol by rain was initiated two years ago in the Cloud Physics Laboratory of the Water Survey. During this period, problems in aerosol generation, contamination, and measurement were solved. A raindrop acceleration tower was constructed and drop generators were designed and built. Various experimental procedures have been developed, sources of contamination identified and removed, and reliable data are now being obtained.

The experimental results included the measurement of the amount of material captured by a single drop which passed through a monodisperse aerosol, and the dependence of the capture on the electric charge of the drop. The following section of this report is a summary of these results which were presented at the Precipitation Scavenging Meeting, Hanford, Washington, (Adam and Semonin).

Motivation

Aerosols are removed from the air by precipitation in four different ways: the impaction and capture, or collection of particulates by raindrops; the consumption of particulates as condensation nuclei; the attachment of particulates to cloud and raindrops by Brownian motion; and other molecular interactions. It has been calculated theoretically by Langmuir and Blodgett (1945) , and determined experimentally by Engelmann, et al (1966), that impaction and capture is an efficient process for the removal of particles larger than a few microns diameter. However, extrapolation of these results to submicron size particles shows effectively zero removal by this method. In an attempt to extend the range of experimental collection efficiencies of raindrops for particles below one micron, a new technique incorporating a biological aerosol of the type used by Sood and Jackson (1969) to study scavenging by snow has been devised.

Procedure

The experimental apparatus, as shown in figure 15, consists of an aluminum raindrop acceleration tower 12.2-m tall and one meter in diameter. The lower two meters of the tower is sealed to form an aerosol chamber. The relative

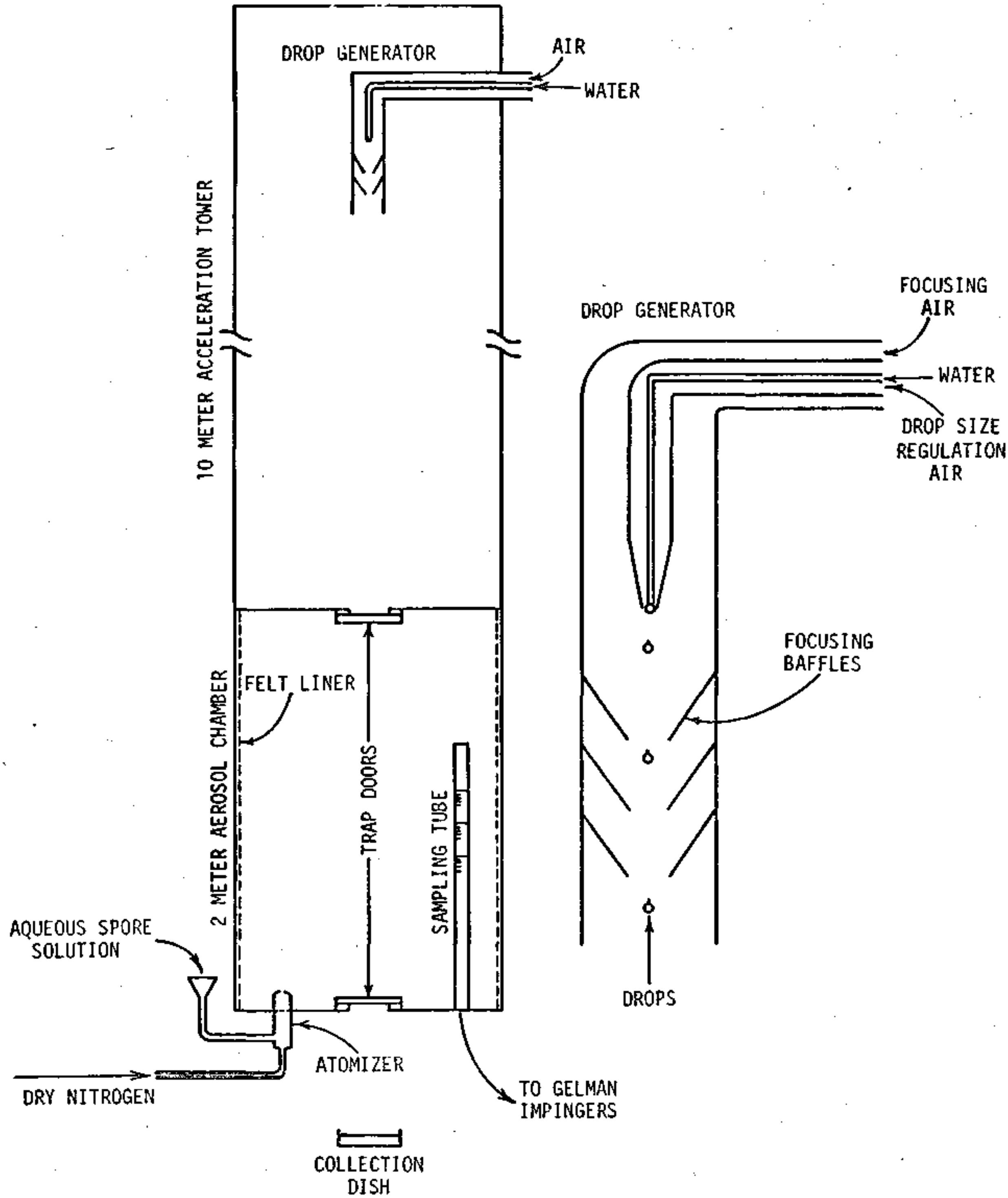

Figure 15. The experimental apparatus for the determination of single drop collection efficiency.

positions of the chamber trap doors, the aerosol atomizer, and the sampling tube are also shown.

A drop generator is mounted within the tower at a height chosen to insure that the drops achieve terminal velocity before entering the aerosol chamber. Drops larger than 2-mm diameter are dripped from a hypodermic needle. Smaller drops are blown from the tip of a capillary tube using the generator shown in detail in figure 15. The drop size is determined by both volumetric collections and direct optical measurement. The drops can be charged electrically by induction and the charge magnitude measured with a coulombmeter.

The amount of submicron particulate matter scavenged by a single simulated raindrop passing through the aerosol chamber is very small. Detection difficulties have been overcome by the use of bacteria spores as the aerosol constituent. After passing through the aerosol, the scavenging drop is collected on a petri dish, incubated, and the colonies originating from the individual spores are counted. Bacillus subtilis spores are presently being used. These spores are rod shaped, being 0.7-μm in diameter by 1.2-μm long. An aerosol of the spores is formed by atomizing a dilute aqueous solution of the spores with pressurized air. Extreme care is taken to insure that the spores are monodisperse. The aerosol concentration is determined at various times during an experimental run by passing a known volume of air through a midget impinger whose collection efficiency for the spores has been determined.

To obtain accurate experimental results, several precautions must be taken. To insure a clean environment before the experimental run begins, the area around the tower is cleaned and disinfected. The tower and aerosol chamber are ventilated with clean air to remove residual spores and dust. All glassware, agar, the drop generator, and its water are autoclaved. Control air samples are taken around the tower and chamber to obtain a background spore concentration. The concentrated spore solution is prepared and atomized by someone other than the experimenter to further reduce the possibility of contamination.

A typical experimental run proceeds as follows. The drop generator is positioned and adjusted to produce a specific size drop falling at terminal velocity within the aerosol chamber. The aerosol is then generated. The initial concentration is approximately 800 spores per cubic centimeter and decays exponentially with a half-life of about 40 minutes. The next approximately 15-30 minutes of the highest aerosol concentration are divided into various series of drop collections. An aerosol concentration measurement is made at the beginning and end of each series. Within each series, a large number of drops with or without electrical charge is passed through the aerosol. Each drop is collected on a petri dish placed 1.2-m below the aerosol chamber. The dishes are then incubated long enough for each spore to develop into a colony of cells approximately 30-μm in diameter. At this size the colonies are large enough to be easily counted optically with a microscope but do not overlap and lose their individual identities. The collection efficiency defined as the ratio of the number of particulates scavenged from the aerosol to the total number in the volume through which the drop falls is then calculated for each drop.

Results

The scavenging efficiency for uncharged drops is shown in figure 16. The results shown are the average scavenging efficiency for over 50 drops of each size, produced, collected, and examined individually. The increase in scavenging of the uncharged aerosol by charged drops is shown in figure 17. The scavenging efficiency increases linearly with increasing charge from its value in the uncharged case (correlation coefficient greater than 0.95).

In all cases, the aerosol charge was monitored and no charge greater than 10   coulombs per spore was observed. Only for the 3.74-mm drops was there any tendency for increased collection with one sign of charge. This would indicate that possibly the aerosol had a small net charge for this run.

Implications

The experimental technique described is both accurate and sensitive for measuring scavenging by raindrops. The ease of generation, detection, and decontamination, the uniformity of size, and the ease of concentration determination makes bacteria spores well suited as the aerosol particulate. The only difficulty encountered is finding other suitable spores, smaller than 1-μm, which are viable after atomization and which have a relatively low natural occurrence.

Using the measured scavenging efficiencies, an estimate of the amount of material in the 1-μm size range removed by natural rain can be made.

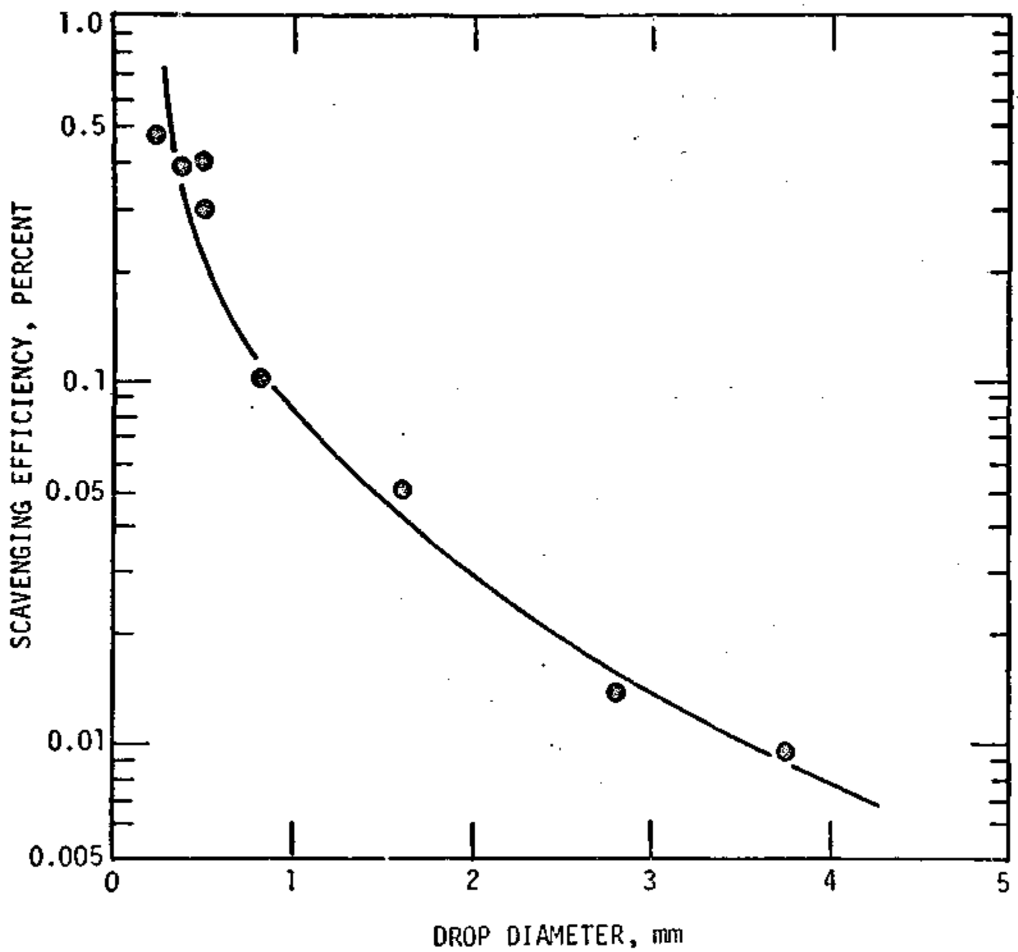

Figure 16. The scavenging efficiency of raindrops for 1-μm spores without electrical effects.

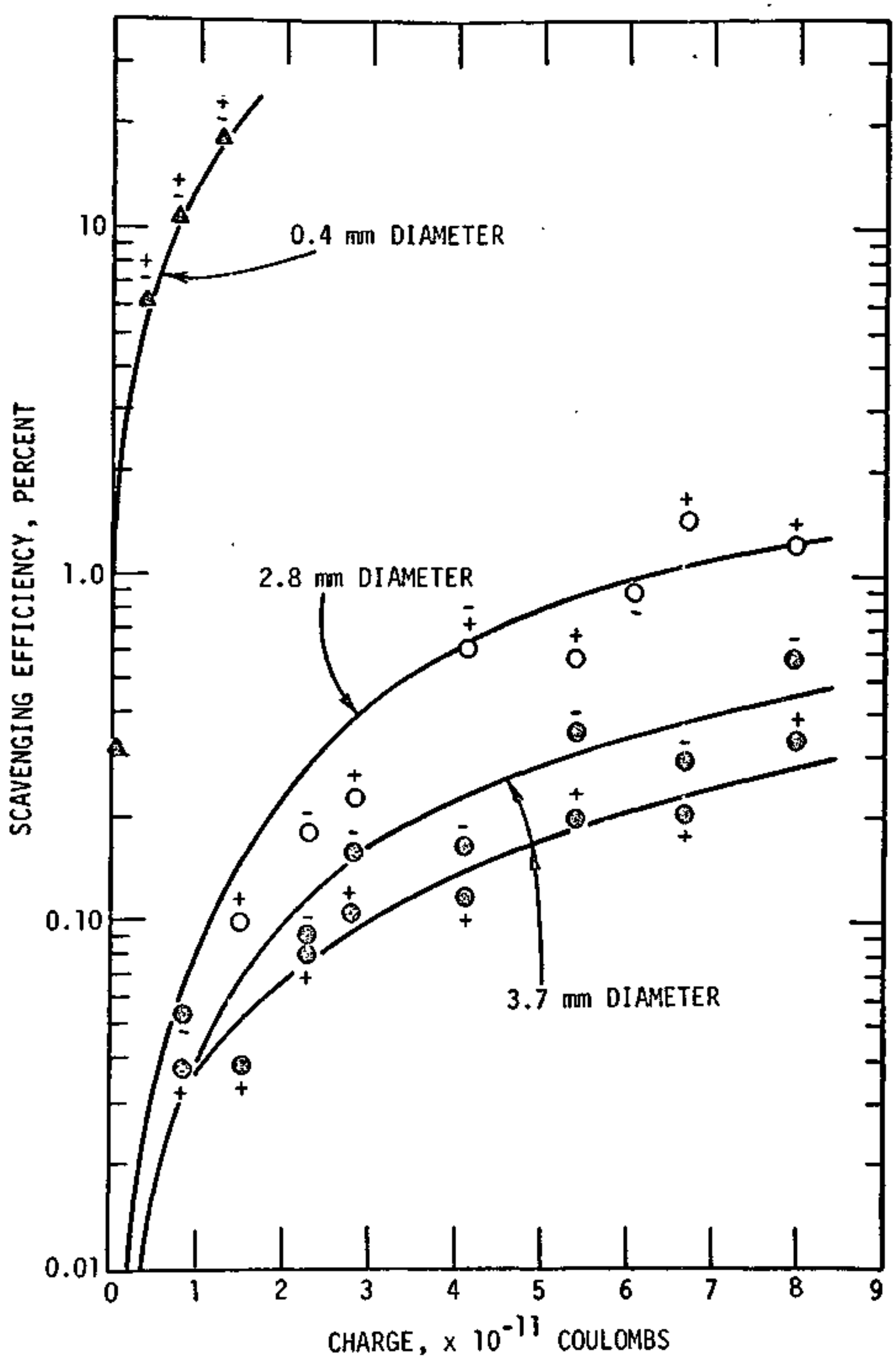

Figure 17. The scavenging efficiency of raindrops for 1-µm spores as a function of drop electric charge.

It is assumed: 1) that rainfall has a Marshall-Palmer drop distribution for drops greater than 0.5-mm; 2) the drops are uncharged; and 3) they are falling at terminal velocity. A simple calculation then shows that less than 1% of the particulates are removed per hour in a 5 mm per hour rain, and only 4.5% are removed in a 100 mm per hour rain.

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APPENDIX A

THE ILLINOIS TRACER EXPERIMENT - 1970

A SUMMARY REPORT OF ACTIVITIES
CONDUCTED BY ATMOSPHERICS INCORPORATED

I T R E X. . . . .

THE ILLINOIS TRACER EXPERIMENT - 1970

A SUMMARY REPORT OF ACTIVITIES
CONDUCTED BY ATMOSPHERICS INCORPORATED

Prepared for

The Illinois State Water Survey
Atmospheric Science Section
Urbana, Illinois

by; Thomas J. Henderson
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Atmospherics Incorporated
4981 East Dakota
Fresno, California 93727

15 August 1970

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ABSTRACT

The period 15 May 1970 through 30 June 1970 provided an extension of activities under Project ITREX - The Illinois Tracer Experiment. Under subcontract with the Illinois State Water Survey, Atmospherics Incorporated of Fresno, California provided equipment, personnel and services as part of specific objectives related to the rainout of tracer element material from thunderstorms in Central Illinois.

Tracer material was released from the aircraft during six thunderstorm test cases. Measurements of ice and condensation nuclei concentrations were logged on a number of additional flights and general meteorological data were noted as part of the total flight mission. As a secondary consideration to this program, project photographs were obtained which provide a general visual summary of tracer element delivery and associated weather phenomena.

This report summarizes the operational phases provided by Atmospherics Incorporated as part of the total 1970 ITREX mission and suggests a number of conclusions and recommendations which might be useful in the design and operation of future tracer element experiments.

LIST OF TABLES AND FIGURES

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I BACKGROUND AND INTRODUCTION

The uncertainties associated with the scavenging mechanisms of rainfall, as well as the space-time considerations of thunderstorm inflow-outflow, have long been a primary area of concern for the atmospheric scientist. A definitive description of the mechanisms involved in these atmospheric processes is difficult. However, the aerial placement of tracer element material and the subsequent analysis of time related rainfall offers an important method for indirectly determining the efficiency of precipitation mechanisms.

The Illinois Tracer Experiment (ITREX) represents a continuing program for determining the direct scavenging efficiency of thunderstorm precipitation and the turnaround time from release of material in the inflow areas at cloud base to fallout in the precipitation as measured at ground stations. Initial efforts along these lines began several years earlier in Oklahoma and continued in 1969 as a result of total project movement to Illinois. During 1970, the field program included the coordinated use of personnel from the Illinois State Water Survey, the University of Michigan, the National Center for Atmospheric Research and Atmospherics Incorporated.

The Central Illinois Precipitation Measurement Network is one of tne most concentrated and significant networks in the world. The location and extent of this network west of Champaign-Urbana, Illinois, provides the proper platform from which many investigations of this type may be launched. During the 1970 program, the University of Michigan field personnel were based near the center of the network at Clinton. All other personnel operated from project headquarters at the Willard Airport near Champaign. A map of the operational area is shown in Figure 1.

Under sub-contract with the Illinois State Water Survey, Atmospherics Incorporated provided aircraft and personnel as part of the total ITREX - 1970 program. For the operational period 15 May through 30 June 1970, the placement of tracer element material into selected areas of thunderstorms is described in the following Sections II through VI. Additionally, the measurement of ice and condensation nuclei concentrations during each of the routine flight missions provides an area of further discussion in this operational summary.

Mr. Thomas J. Henderson and Mr. Donald W. Duckering acted as project supervisor and pilot-meteorologist for the activities accomplished by Atmospherics Incorporated.

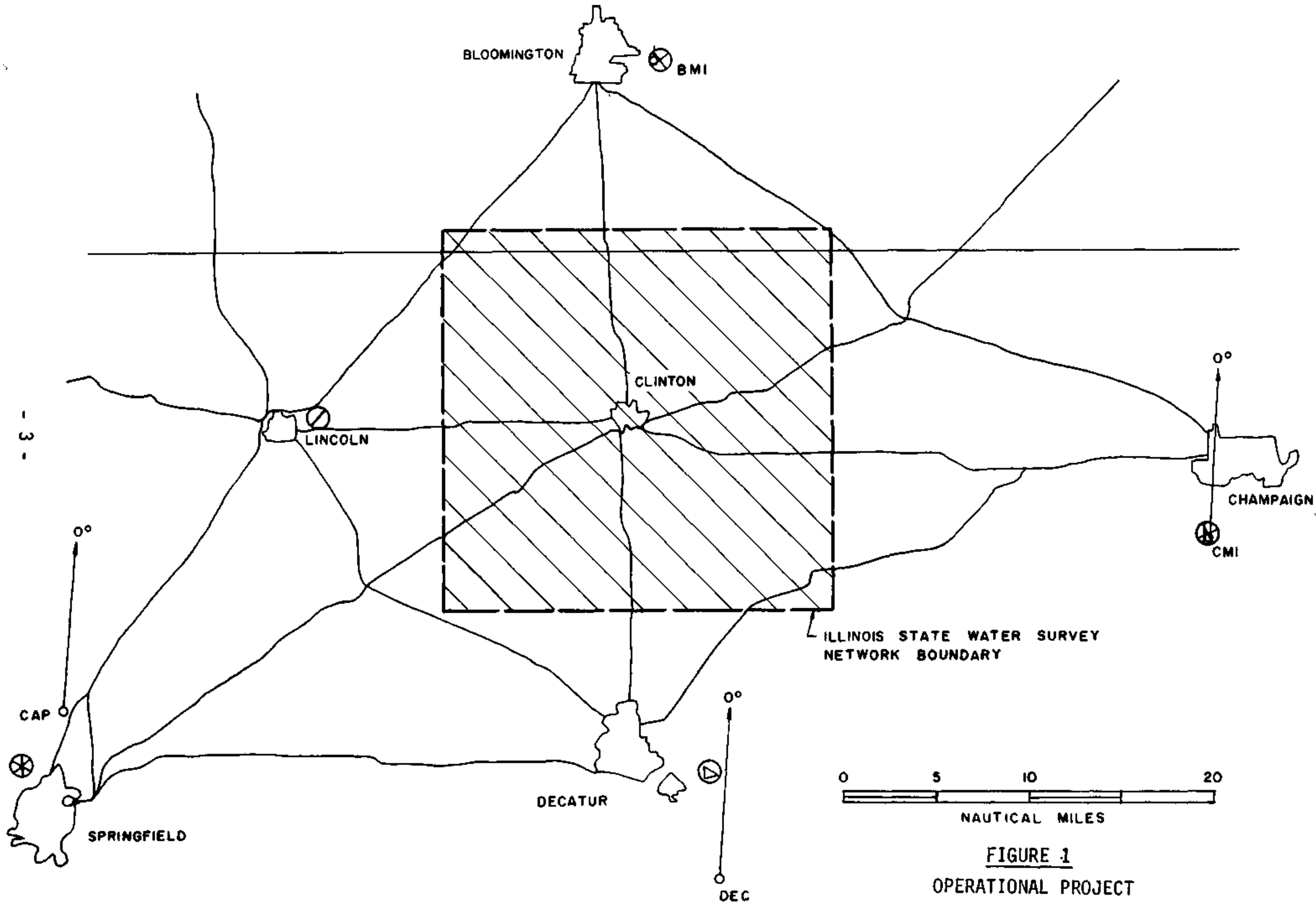

FIGURE 1

OPERATIONAL PROJECT

ITREX - 1970

II OBJECTIVES

In a broad sense, the overall mission was designed to disperse a tracer element material in such a way that its detection could be accomplished through examination of precipitation which subsequently fell from the treated cloud. Within this total effort the objectives as assumed by Atmospherics Incorporated can be stated as follows:

A. Provide an aircraft and experienced crew of pilot and meteorologist with a minimum of 5 years experience in thunderstorm flying to delivery tracer material in specific areas appropriate to the subsequent fall of precipitation over the ISWS precipitation gauge network.

B. Utilize pyrotechnic generated indium chloride as the tracer element for dispersal in the appropriate areas near cloud base.

C. Measure and record the pertinent environmental parameters around the thunderstorm chosen for application of material. These parameters will include temperature, humidity, elevation of cloud base, updraft position and velocity, ice and condensation nuclei concentrations, aircraft position, and notes on the general physical characteristics of the environment surrounding the test case clouds.

D. Provide project photographs covering the conduct of the mission as accomplished by Atmospherics Incorporated.

E. Prepare a summary report of activities within the framework of tracer element delivery mission and delineate the meteorological conditions associated with each test case.

Within the framework of the above objectives, additional observations were to be made for purposes of describing the general cloud characteristics and how these might compare with those observed by Atmospherics Incorporated personnel in other areas of the United States and abroad.

III EQUIPMENT

Equipment provided by Atmospherics Incorporated and available for use as part of the requirements under this mission included the following:

A. Turbocharged Aztec "D" Aircraft
   1. 2-360 channel Nav-Com systems
   2. Dual Omni Navigation system
   3. DME (Distance Measuring Equipment)
   4. Transponder (L-band)
   5. ADF
   6. IVSI (Instantaneous Vertical Speed Indicator)
   7. Motorola Communications (151.625 MHz)
   8. Cloud Seeding Pyrotechnic Racks and Controls

B. Meteorological Instrumentation
   1. Temperature (Rosemount - digital readout)
   2. Humidity (Electronic Psychrometer - Mee Industries)
   3. LWC (Johnson-Williams)
   4. Ice Nuclei (Portable Cold Box)
   5. Condensation Nuclei (Gardner Small Particle Detector)
   6. Recorders (Rustrak)

C. Miscellaneous
   1. Cameras (Rolleiflex - 2¼ x 2¼)
   2. Flight and Operational Forms
   3. Support tools and accessories

IV FLIGHT MISSIONS

A total of 27 flights were logged by Atmospherics Incorporated during ITREX - 1970. These included flights conducted for purposes of aircraft ferry, nuclei measurements, general observations and the application of tracer element material. A summary of all flights is shown in Table 1.

Six test cases for tracer element application were logged during the operational period. Following is a brief narrative description which covers each of these test cases.

TEST CASE #1 - 24 May 1970

The general weather indicated a rather weak frontal system north and west of the operational area with numerous cumulus and cumulonimbus forming over much of the area by early afternoon. The AI aircraft was alerted for flight and departed Champaign at 1357. Aerial observations were conducted for about an hour before landing at Bloomington.

After a standby alert, the aircraft departed Bloomington at 1552 and proceeded toward Lincoln. Small cumulus cells were observed south and west of Bloomington but cell movement was unsatisfactory for proper location over the network. North of Decatur near the south edge of the network a few small cumulus cells were observed building in a line running WSW-ENE into the southern portion of the network. Inflow to these individual cells was noted along the NE edges and application of pyrotechnic generated indium was initiated at 1804. The flight altitude remained at 6,000 feet msl during the total burn and inflow velocities were logged at 500-1000 fpm.

It is important to note that new cumulus cells were building and dissipating along the total line throughout the application period. Small rain shower areas were noted further NE from the dispersal area and attempts were made to apply the material to the specific area of individual cell growth which would be appropriate to subsequent precipitation fallout over the SE corner of the

TABLE 1

ATMOSPHERICS INCORPORATED
FLIGHT SUMMARY
ITREX - 1970

FLT. NO.	DATE	TAKE OFF	LAND	FLT. TIME	CUM. TIME	REMARKS
1	5/17/70	0642	1100	4.3	4.3	Ferry flt - Fresno - Denver, Colo.
2	5/17/70	1336	1804	4.5	8.8	Ferry flt - Denver - Champaign, Ill.
3	5/18/70	1425	1535	1.2	10.0	Ferry flt - Champaign - Marion,Ill.
4	5/19/70	0040	0145	1.1	11.1	Ferry flt - MWA-CMI (01in LiCl flares)
5	5/19/70	1037	1126	0.8	11.9	Familiarization flt over local area
6	5/21/70	1210	1315	1.1	13.0	Flt. test of equipment and radio check.
7	5/23/70	1426	1700	2.6	15.6	Observational flt - conditions unsat.
8	5/24/70	1351	1447	0.9	16.5	Observational flt - Landed Blooming-ton.
9	5/24/70	1552	1857	3.1	19.6	Test Case #1 - Indium put in cell line.
10	5/26/70	1051	1111	0.3	19.9	Flt. test of LiCl flares
11	5/26/70	1144	1207	0.4	20.3	Flt. as chase plane of NCAR A/C - flare test.
12	5/29/70	1417	1507	0.8	21.1	Observational flt - landed Decatur
13	5/29/70	1647	1725	0.6	21.7	Observational flt - cond. unsat.
14	5/30/70	1820	1849	0.5	22.2	Observational flt - cond. unsat. (Test Case #2)
15	5/31/70	1553	1630	0.6	22.8	Observational flt - cond. unsat.
16	5/31/70	1801	1820	0.3	23.1	Return flt from Decatur
17	6/1/70	1430	1734	3.1	26.2	Test Case #3 - Indium put in line of RW's.
18	6/5/70	1344	1541	1.9	28.1	Flt to dispense indium & AgI for sample coll.
19	6/14/70	1334	1445	1.2	29.3	Test Case #4 - Indium put in line of active RW
20	6/15/70	1452	1554	1.0	30.3	Test Case #5 - Indium and LiCl put in severe TSTM.
21	6/17/70	1439	1511	0.5	30.8	Observational flt - landed Lincoln

TABLE 1 - CCont.)

FLT. NO.	DATE	OFF	LAND	TIME	TIME	REMARKS
22	6/17/70	1720	1749	0.5	31.3	Observational flt - returned to CMI
23	6/20/70	1642	1729	0.8	32.1	Test Case #6 - Indium & LiCI rain scavenging
24	6/30/70	1147	1430	2.7	34.8	Ferry flt - Champaign to Marion, sampling over St. Louis
25	7/31/70	1451	2003	5.2	40.0	Marion - Pueblo
26	8/1/70	0744	1228	4.7	44.7	Pueblo - Bishop
27	8/1/70	1255	1343	0.8	45.5	Bishop - Fresno

network. Observations following application indicated the space-time considerations of the flight path were satisfactory for deposition of material in a measureable portion of the network.

Ice nuclei concentrations measured during this flight were noted from less than one per liter to about 5 per liter. Aitken nuclei concentrations were above 10^4 cc^{-1} at takeoff near Bloomington but dropped to 1400 cc~ at 5500 feet msl near Lincoln and 3200 cc~ near the area of tracer material application at cloud base. Cloud condensation nuclei (CCN) at cloud base were around 700 cc^{-1}. A map of the flight path for Test Case #1 is shown in Figure 2.

TEST CASE #2 - 30 May 1970

The synoptic situation indicated a high pressure system over the East Coast with a stationary front from Minnesota to Texas. A low pressure area was noted in the Dakotas. Scattered light rain showers were observed throughout Illinois most of the day with warm, humid and rather stable air around the network area.

A flight was initiated at 1320 but observations indicated no cumulus developments suitable for application of material in the inflow areas at cloud base. The NCAR Queen Air dispersed lithium chloride at higher levels of the cloud and Test Case #2 was declared on the basis of this single application.

TEST CASE #3 - 1 June 1970

The morning surface map indicated a low pressure center over the Great Lakes region with a cold front to Central Texas. High pressure systems were noted both east and west of the operational area. Overcast stratocumulus was observed most of the day and light rain areas were noted by the radar.

Aircraft operations were initiated at 1430 and aerial observations began over the SE corner of the network. By 1600 the aircraft had moved through the area west and SW of Decatur without finding sufficient cell growth. Shortly thereafter a few cumulus developments began to show more vigorous vertical development along

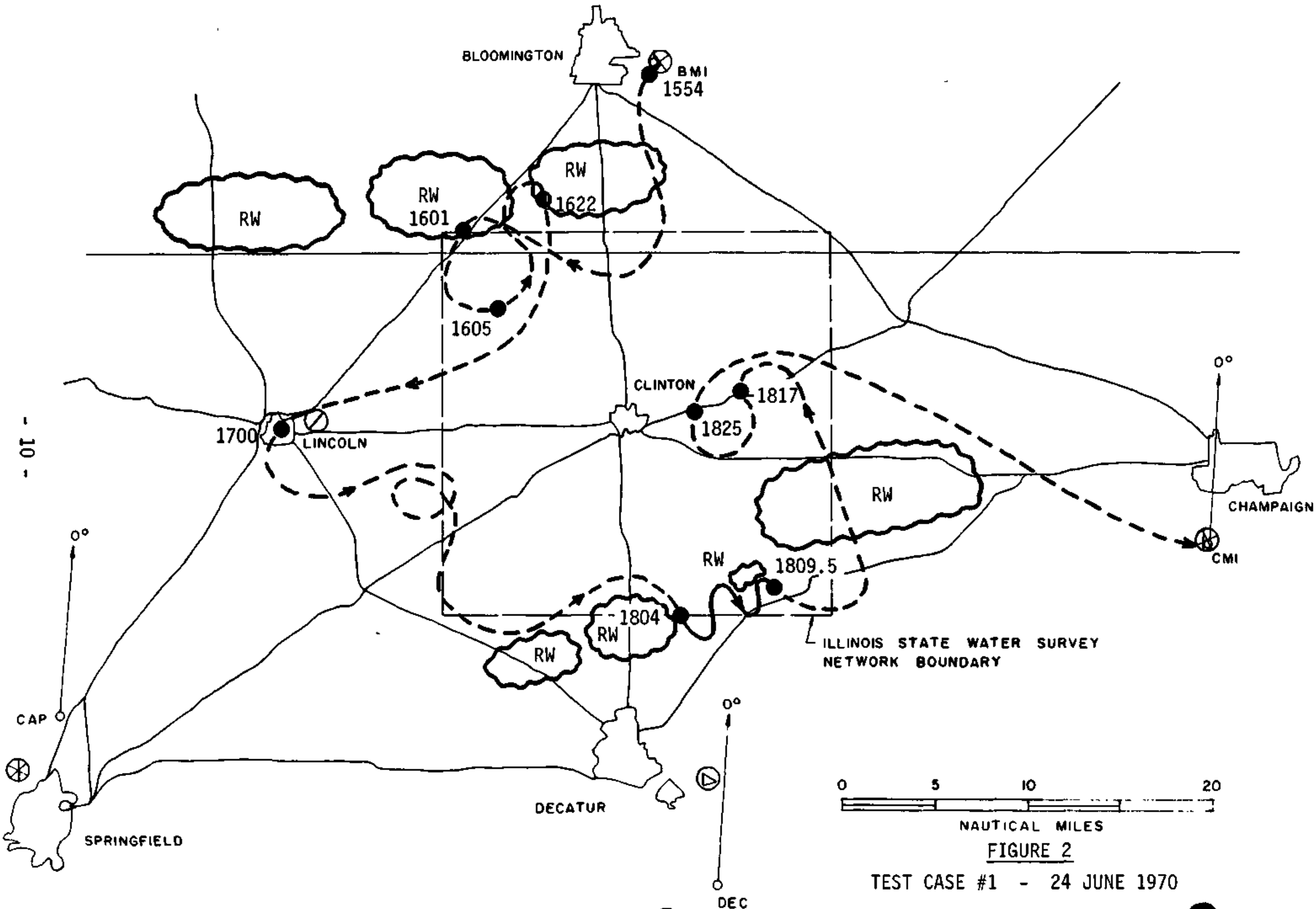

FIGURE 2

TEST CASE #1 - 24 JUNE 1970

a line from 15 miles west of Decatur to near Clinton.

At 1644 updrafts to 500 fpm were measured along the eastern edge of a precipitation producing cell just entering the SW corner of the network. The actual application was made between Warrensburg and the SW corner of the network with minimal updrafts continuing throughout the total application period. Cell movement continued toward NE and observations from the aircraft indicated precipitation from the treated cell did pass over a large portion of the network. The NCAR aircraft dispersed pyrotechnic generated lithium at levels near cloud top.

Of particular interest during this application was the observed multiple turrets developing on many sides of the growing cumulus. Specifically in the areas from NE through N through WSW, these new turrets appeared to be the most vigorous. The individual cells did not appear to contain the physical characteristics usually associated with either the squall line or air mass types. However, the general particulate concentration throughout the area is so high, it is difficult to observe large scale physical features of an individual cell or line of cells.

A map of the flight path for Test Case #3 is shown in Figure 3.

TEST CASE #4 - 14 June 1970

The surface map positioned a stationary front from South Carolina through Illinois to Nebraska. A cold front was noted west of the operational area and the morning sounding was very unstable. Fog was noted in the Champaign area but dissipated before noon. Cumulus cells developed soon thereafter.

A flight was initiated at 1334 and the area immediately west of Clinton was probed for strong updrafts. The squall line associated with the cold front was noted in this area and numerous individual cumulus cells were observed along a N-S line over the total network. Flight conditions were extremely poor with visibility down to 1-2 miles in fog. Only light updrafts were found along the eastern edge

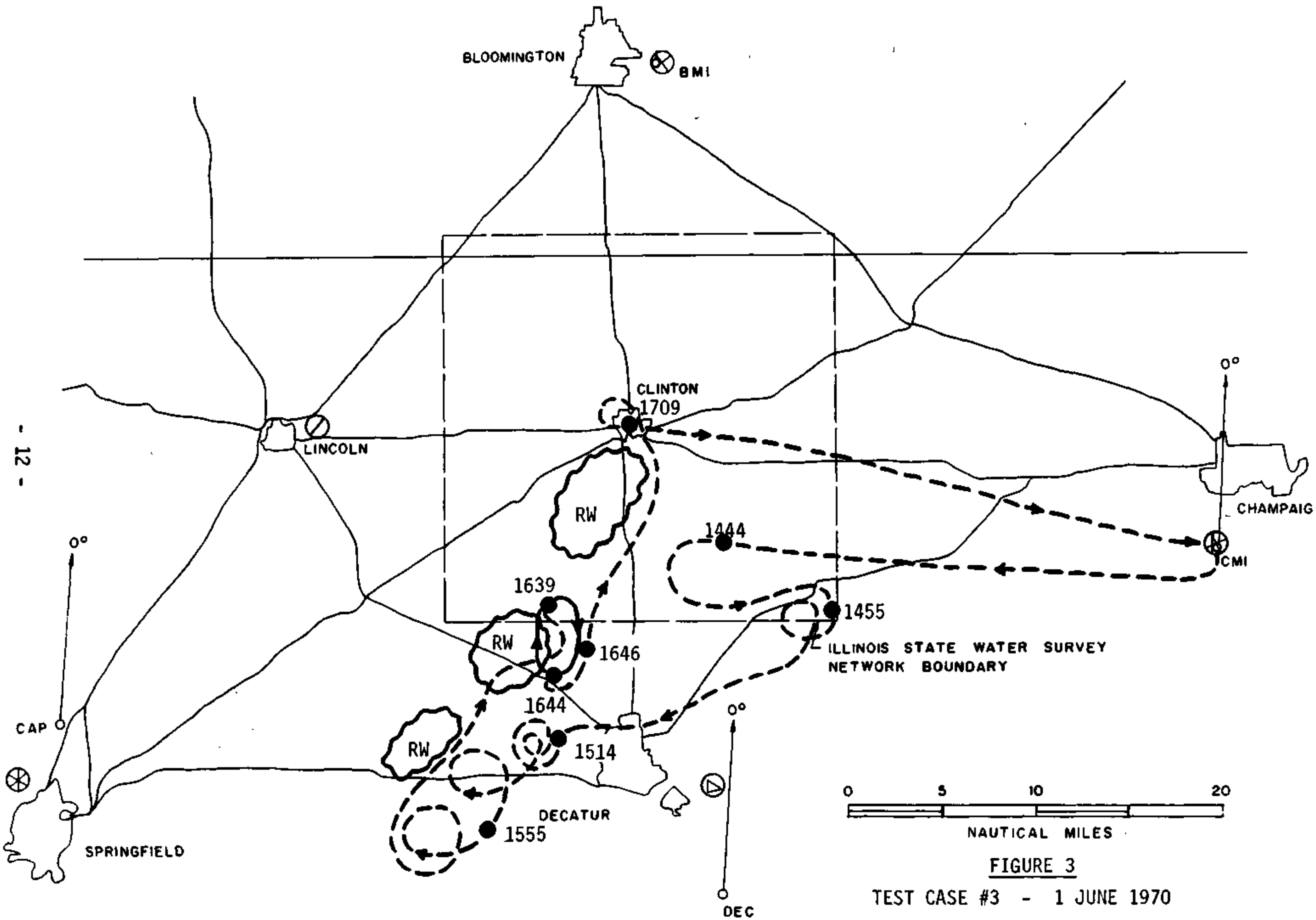

FIGURE 3

TEST CASE #3 - 1 JUNE 1970

of the system and the low visibility plus strong electrical activity prevented penetration to the western side of the system. Tornadoes were reported 10 miles east of Springfield and south of Peioria.

Application of indium tracer material began at 1416 along the eastern edge of the line. An immediate return to Champaign was advised due to poor flying conditions. Tornado and rain damage was reported throughout many areas of Central Illinois with trailers, houses, barns, trees and crops suffering severe damage. A map of the flight path for Test Case #4 is shown in Figure 4.

TEST CASE #5 - 15 June 1970

The surface map indicated a stationary front along an arc from Virginia through northern Illinois to the Dakotas. The air was warm and humid during the morning hours and scattered rain showers with towering cumulus cells were noted by early afternoon.

A flight was initiated at 1452 and the aircraft proceeded to a point immediately NW of Clinton for intersection with a line of cumulus cells running north and south along the western edge of the network. A strong thunderstorm was noted in this area with vigorous cloud-to-ground lightning. Hail was suspected by the "green area" appearance within the cell.

Updrafts along the leading edge of the system were measured at 1500-2000 fpm and injection of indium tracer material was initiated at 1520. About this time Michigan Base at Clinton reported they were inundated by the first thunderstorm and precipitation from the treated cell followed soon thereafter. The aircraft returned to Champaign soon after the injection of tracer material and heavy thundershowers soon moved over the airport. Activity throughout the area was intense with hail reported in several locations. A 40x150' section of the Decatur Firestone Plant collapsed and many areas reported 4-5 inches of rainfall with local flooding.

A map of the flight path for Test Case #5 is shown in Figure 5.

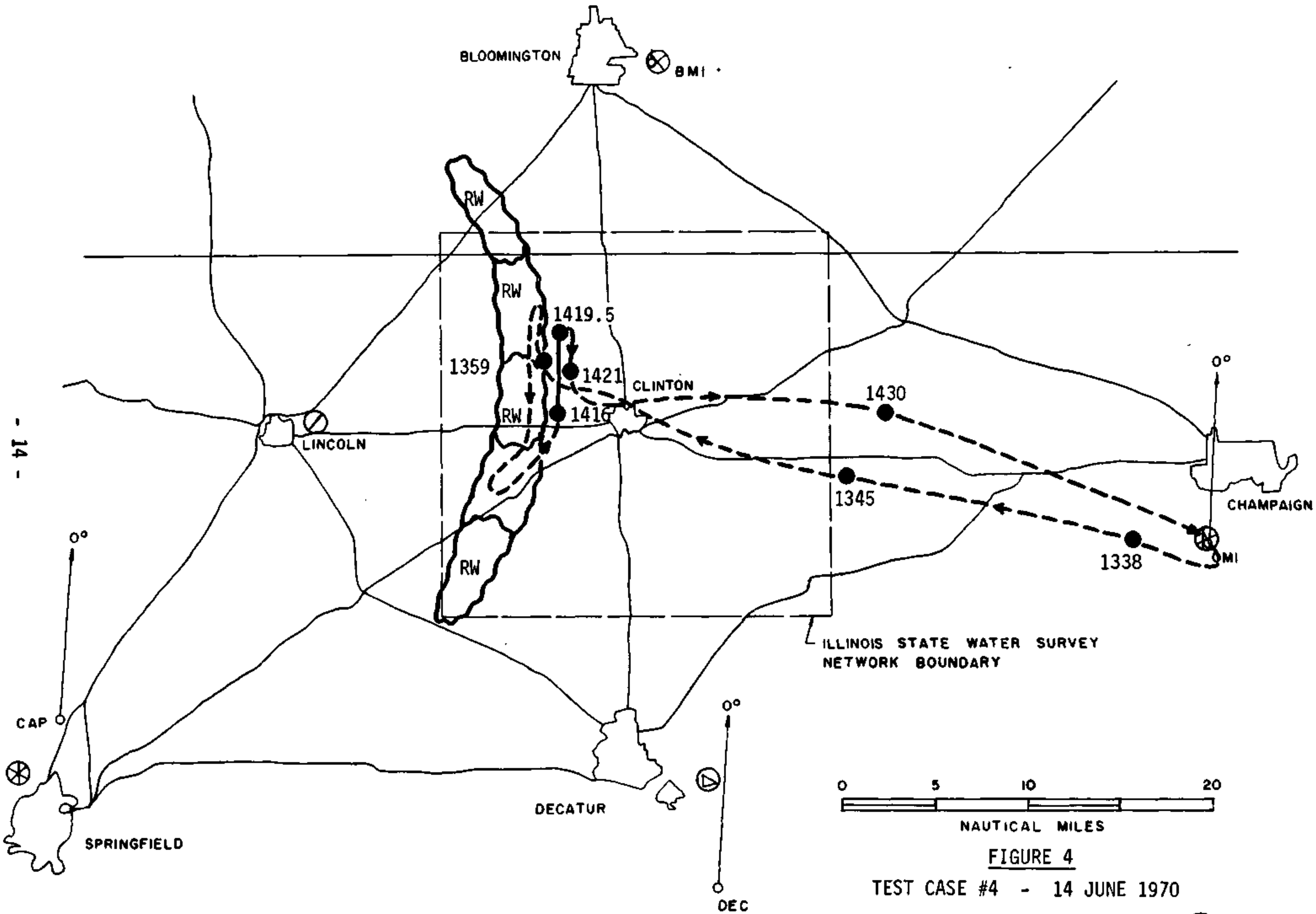

FIGURE 4

TEST CASE #4 - 14 JUNE 1970

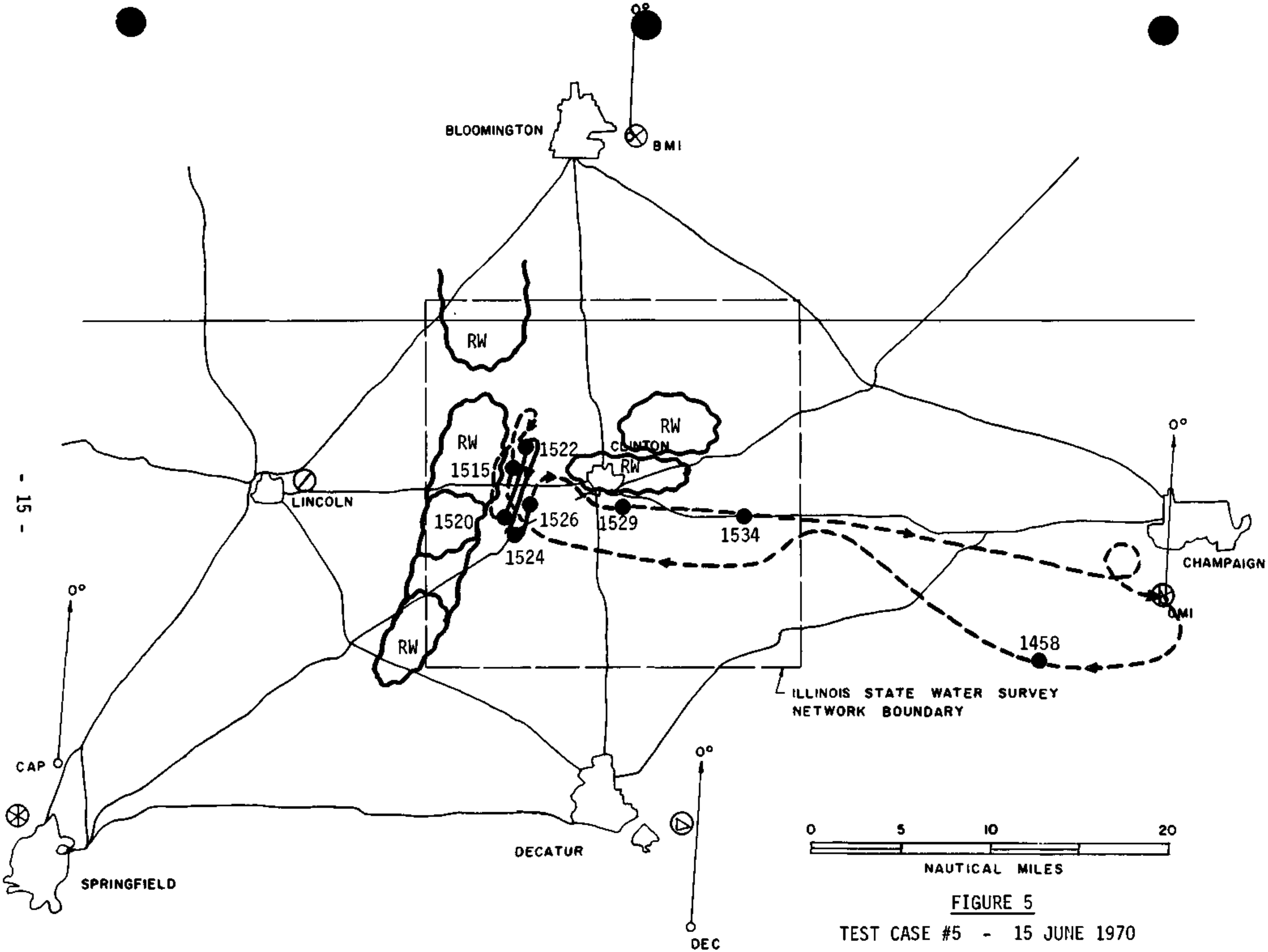

FIGURE 5

TEST CASE #5 - 15 JUNE 1970

TEST CASE #6 - 20 June 1970

The surface map positioned a low pressure system over Southern Minnesota with a weak front from Ontario to Missouri. Variable cloudiness was noted in the morning with light rain showers from solid overcast conditions in mid-afternoon. A few heavier rain showers were noted in late evening.

A flight was initiated at 1642 and the aircraft proceeded from Champaign westerly to a point SW of Clinton near the western edge of the network. Application of lithium tracer material began at 1706 as part of a direct rain scavenging experiment along a W-E path through the center of the target south of Clinton. The aircraft returned directly to Champaign after application of material A map of the flight path for Test Case #6 is shown in Figure 6.

In addition to the Test Cases initiated for purposes of injecting tracer element material into a specific cumulus development, one flight was made on 5 June 1970 for purposes of measuring particle size distribution with instrumentation aboard the NCAR aircraft. This mission was accomplished above a low stratus deck where the air was very stable and very little turbulence was noted. In separate experiments, lithium and silver iodide were dispersed from the AI aircraft and the following Queen Air provided the sampling and detection capability. It is interesting that the ice and condensation nuclei concentrations remained low and very uniform above the top of the stratus layer but rose abruptly as soon as the aircraft descended below the stratus base. Analysis of the filters in this experiment was provided by the University of Michigan group.

The final flight accomplished by AI during the ITREX - 1970 mission occurred on 30 June 1970. As part of the aircraft ferry flight to Southern Illinois for use on the Shawnee Hills Project, a particulate sampling mission was accomplished over the St. Louis metropolitan area. This flight produced some of the most important and significant preliminary information obtained during the total mission.

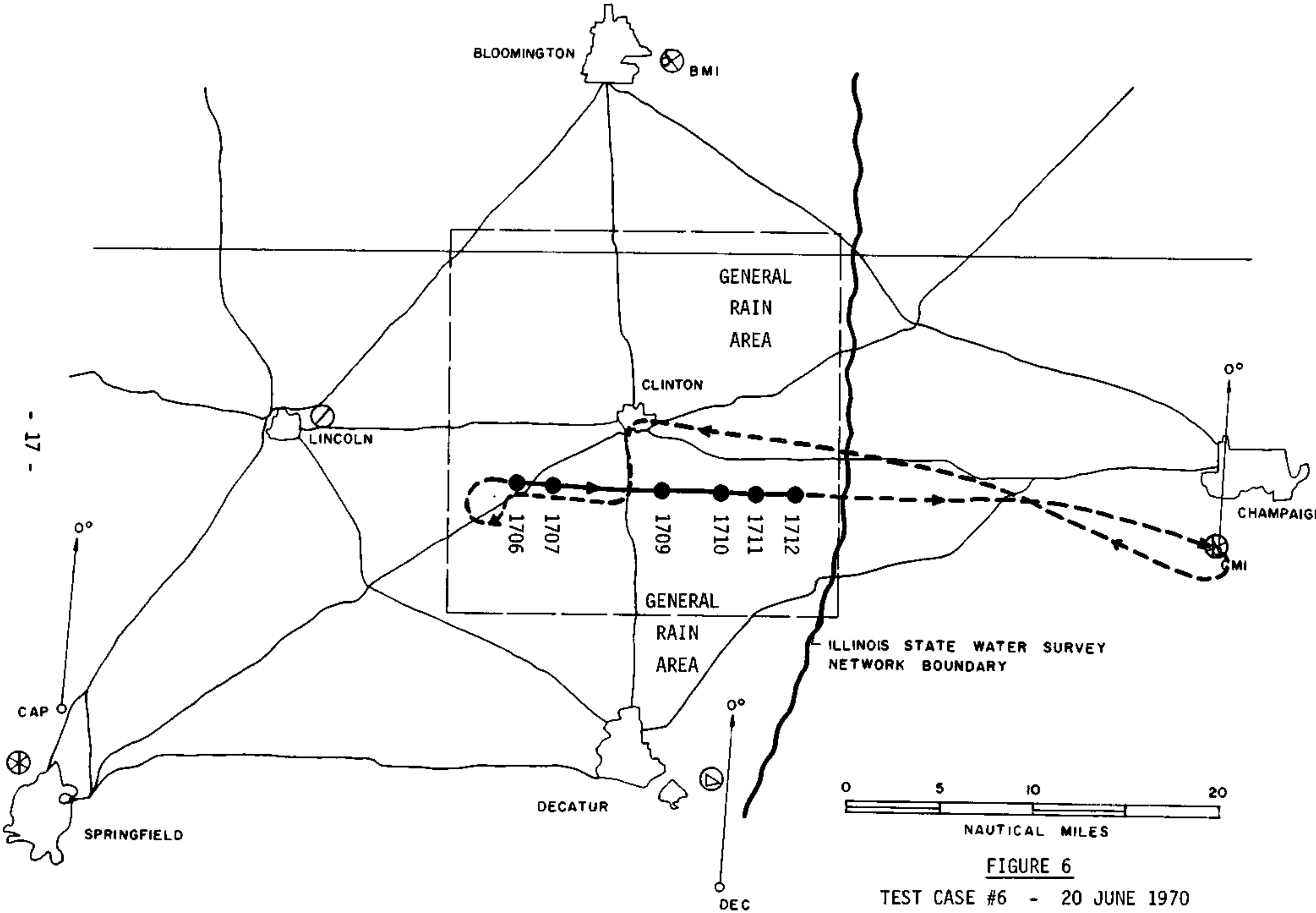

FIGURE 6

TEST CASE #6 - 20 JUNE 1970

Ice and condensation nuclei concentrations were measured at 21 sample points over and near St. Louis. Flight altitudes included both 1500 feet and 3000 feet msl. At most of the sample point locations the condensation nuclei concentrations were above 10^4 cc^{-1} and in a few cases were greater than 10^5 cc^{-1}. Ice nuclei concentrations ranged up to 1000 per liter. Of particular importance to the fields of atmospheric and aerosol science was the extremely strong iodine odor over a substantial area immediately east of St. Louis.

The flight across St. Louis had been planned for a WSW-ENE oriented "air free" corridor centered just north of the business district. From Pere Marquette the flight proceeded to a point near Pacific, Missouri where a heading on the Troy V0R was initiated. The primary measurement path was from a point west of Valley Park at 3000 ft. msl ENE to the Troy V0R and then on a parallel return heading at 1500 feet msl.

On a hot humid mid-summer day near St. Louis there is strong evidence that a heat "bubble" exists over the metropolitan area and the "plume" of both heat, humidity and particulate concentration associated with this area is well established downwind from the area itself. The implications associated with this phenomenon are so numerous and significant that an extensive and more definitive study must be made of the area as soon as possible.

Daily operational summaries, flight logs and nuclei measurement dat- obtained during the various flight missions are submitted as supplements to this summary report.

V RESULTS AND CONCLUSIONS

The Atmospherics Incorporated portion of ITREX - 1970 included the dispersal of tracer element material along the inflow area at the base of four moderate to large cumulus developments. Additionally, one test case was logged where material was dispersed directly in the precipitation so measurements related to scavenging could be made at ground level. For purposes of delineating particle size distribution from pyrotechnic generated material, one flight was coordinated with the University of Michigan personnel and the NCAR flight crew. During all normal program flights, measurements were made of ice and condensation nuclei concentrations over many locations of the operational area. On the final trip to Marion, Illinois, specific measurements of temperature and humidity, as well as ice and condensation nuclei concentrations, were made over the St. Louis metropolitan area.

Coordinated radar and flight activities are extremely important in missions of this type and personnel associated with ITREX - 1970, provided the synergistic mix necessary for maximum results. While cloud conditions always seem to appear insufficient for the desired number of experiments, those cases experienced during the 1970 program did provide interesting and significant opportunities for the delineation of fallout patterns over the precipitation network. Of particular importance were Test Cases 3, 4, and 5 where tracer element material applied in the proper location at cloud base should have resulted in a reasonable plume pattern over the precipitation gauge sites.

It is important that any platform utilized for dispersal of material is positioned in the proper location with respect to the specific inflow related to the precipitation mechanism and not to an area where inflow has little or no relationship to that volume of cloud which initiates precipitation. In the case of squall lines, this important inflow appears to be along the leading edge of the line ahead of the precipitation. In air mass type thunderstorms this important inflow area appears along the trailing edge behind the precipitation. There is a third type cumulus development, not seen in Illinois during the 1970 program which has inflow completely surrounding the precipitation and appears similiar to a large rotating vortex with only mild updraft velocities.

Inflow velocities measured during this mission were not excessive in the sense of thunderstorms producing extremely large hailstones. The vertical velocities experienced during the various test cases were often in the range of 500-1,000 ft. per minute. The highest updraft velocity measured was not much more than 2,000 ft. per minute. This compares with thunderstorm updrafts of more than 4,000 ft. per minute measured at cloud base in other areas of the United States. However, similarities between Illinois storms and those in many other areas of the country and abroad do exist, although the visibility in the operational area often prevented clear observations.

From observations made during the various flights, general discussions with project personnel and results from measurements made over the network area, the following conclusions seem appropriate to the Atmospherics Incorporated portion of ITREX - 1970.

A. The ISWS precipitation gauge network, radar facilities, general support equipment, and personnel provided a unique and important test bed for research related to climatology, precipitation mechanisms, weather modification, and a number of general atmospheric phenomena.

B. Although total storm days were disappointingly few, the team effort of groups associated with this project resulted in the dispersal of tracer element material in a few growing cumulus cells which deposited subsequent rainfall over the network.

C. Particulate concentrations in the general aerosol are extremely important parameters in the birth and growth of cumulus cells but the water vapor haze and high humidity throughout the operational area prevented sorting out any relationship between nuclei and visibility.

D. In those cases where visibility allowed reasonably good aerial observations of cloud development, there appeared to be cases where new virgin turrets grow on more sides, and over wider areas of the total cell, than cumulus cells observed in many other areas of the United States and abroad. This is an important consideration in any field experiment or operation which is designed to establish effects from application of cloud seeding material.

E. As in most parts of the world, ice and condensation nuclei concentrations over the total operational area had wide variations in both time and space. However, it was important to note that ice nuclei concentrations near cloud base were generally quite low compared with many other areas. These measurements were somewhat verified by observations of developing cumulus which often produced no signs of glaciation until cloud tops reached temperature levels of less than -20C.

APPENDIX B

REPORTS PREPARED UNDER THE
CONTRACT NUMBER AT(11-1)-1199
U.S. ATOMIC ENERGY COMMISSION

APPENDIX B

COO-1199-1 -- First Progress Report - January 31, 1963 - F. A. Huff
"Study of Rainout of Radioactivity in Illinois"

COO-1199-2 -- Second Progress Report - January 31, 1964 - F. A. Huff
"Study of Rainout of Radioactivity in Illinois"

COO-1199-3 -- SWS Reprint Series No. 46 - F. A. Huff
"Radioactive Rainout Relations on Densely Gaged Sampling Networks"

COO-1199-4 -- SWS Reprint Series No. 45 - F. A. Huff and G. E. Stout
"Distribution of Radioactive Rainout in Convective Rainfall"

COO-1199-5 -- Third Progress Report - January 31, 1965 - F. A. Huff
"Study of Rainout of Radioactivity in Illinois"

COO-1199-6 -- Research Report No. 1 - March 1965 - F. A. Huff
"Radioactive Rainout Relations in Convective Rainstorms"

COO-1199-7 -- Research Report No. 2 - October 1965 - P. J. Feteris
"1964 Project Springfield Studies"

COO-1199-8 -- Fourth Progress Report - October 1965 - F. A. Huff and W. E. Bradley
"Study of Rainout of Radioactivity in Illinois"

COO-1199-9 -- Reprint - Vienna Paper - Symposium on the Use of Isotopes in Hydrology - G. E. Stout and F. A. Huff - November 14-18, 1966
"Rainout Characteristics for Hydrologic Studies"

COO-1199-10 -- Fifth Progress Report - December 1966 - W. E. Bradley and P. J. Feteris
"Study of Rainout of Radioactivity in Illinois"

COO-1199-11 -- Reprint - February 10, 1967 - W. E. Bradley and Gordon E. Martin
"An Airborne Precipitation Collector"

COO-1199-12 -- Reprint - TELLUS - October 1967 - F. A. Huff and G. E. Stout
"Relation Between Ce^{144} and Sr^{90} Rainout in Convective Rainstorms"

COO-1199-13 -- Conference at Chalk River Laboratories, Canada - September 11-14, 1967 - F. A. Huff and G. E. Stout
"Time Distributions of Radioactivity and Chemical Constituents in Rainfall"

COO-1199-14 -- Sixth Progress Report - November 1967 - F. A. Huff, W. E. Bradley, and P. J. Feteris
"Study of Rainout of Radioactivity in Illinois"

COO-1199-15 -- Research Report No. 3 - July 1968 - John W. Wilson and Parker T. Jones, III
"Tracing Tropospheric Radioactive Debris by Isentropic Trajectories"

COO-1199-16 -- SMRP Research Paper No. 74 - June 1968 - Walter A. Lyons and John W. Wilson
"The Control of Summertime Cumuli and Thunderstorms by Lake Michigan During Non-Lake Breeze Conditions"

COO-1199-17 -- Seventh Progress Report - November 1968
"Study of Rainout of Radioactivity in Illinois"

COO-1199-18 -- Eighth Progress Report - November 1969
"Study of Rainout of Radioactivity in Illinois"

C00-1199-19 -- Ninth Progress Report - November 1970
"Study of Rainout of Radioactivity in Illinois"